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TECHNICAL PAPERS

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REGIONAL
TECHNICAL CONFERENCE

"New Designs for Mold Construction"

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MARCH 14, 1967

Benjamin Franklin Hotel
Philadelphia, Pa.

SOCIETY OF PLASTICS ENGINEERS, INC. • PHILADELPHI

"NEW DESIGNS FOR MOLD CONSTRUCTION"

Regional Technical Conference

Sponsored by

Philadelphia Section

Society of Plastics Engineers, Inc.

March 14, 1967

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"NEW DESIGNS FOR MOLD CONSTRUCTION"

Regional Technical Conference of the Society of Plastics Engineers, Inc.

Sponsored by

PHILADELPHIA SECTION

Philadelphia, Pennsylvania

March 14, 1967

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TOOLING ADVANCEMENTS THROUGH THE 60s

435

ALAN S. RIPLEY

International Tools Limited

Windsor, Ontario, Canada

INTRODUCTION

It is proposed for the purpose of this paper to examine first European developments over the early 60s and the mid-50s and by examination of initial concepts, to evaluate and assess advancements made during this period. We can then determine through stage evaluation, what the industry has achieved technically and how we are utilizing this knowledge in present day applications.

Investigations into the manufacture of injection molding machines relating to cycle times showed in 1960 that machine builders had developed to a maximum rate of injection speed of 1/2 second. Slowed down by curing, mold opening and closing times, a minimum dry cycle time of around 4 seconds could be achieved. Fast cycling pre-plasticizer machines, therefore, can only achieve certain limits of production, and we had then to turn to tooling advancements to achieve further technical advantages. During the early 50s two significant developments took place that determined to a large extent future progress in mold design, for injection molded parts.

First, based upon the theory that plastics materials, in general, have a low thermal conductivity, the Italian technologists utilized this feature to advantage and developed the forerunner of insulated runners and sprueless molding in the Italian sprue. This theory is now accepted on an international basis as standard tooling practice (Figure 1).

Secondly, to eliminate dribble at the nozzle of machines, several manufacturers introduced a simple ball valve into the outlet orifice of the machine nozzle. Again, this simple beginning has been the forerunner of implosion nozzles, and by improvements and adaptation of a basic idea, in building pressures before shooting plasticized material into the mold cavities, valve gating followed as a natural sequence. It was only then a natural stage development, along this path of heated extension nozzles, Italian sprues or insulated runners, and ball gated nozzles, to building molds with all the advantages now opened by the "hot runner" or "insulated runner" principle. Theoretically then, we now know that by introducing a controlled flow of plasticized material directly to the mold cavities, the "hot runner" or "insulated runner" virtually becomes part of the heating cylinder of the machine. By this direct method then, we have eliminated the re-grinding of scrap material, and produced a sprueless component. All the design features of 3-plate pin point feeds or edge gated molds have been extracted regarding sprue removal. Therefore, complicated techniques devised to produce a fully automatic mold can now be restricted to the moving half of the tool and adequate temperature control facilities.

Due to the hot runner becoming an extended part of the machine heating cylinder, a controlled flow of plasticized material can now be shot into all cavities immediately injection pressure is applied. All these factors add up to faster cycling times resulting in increased production. Costly finishing processes are also now centered only on deflashing and with quality tooling and correct clamping pressure finishing can be eliminated entirely.

By the mid-50s and early 60s, several European and U.S. companies were taking hot runner molding very seriously and one of the major developments in injection molding techniques came into being.

It is not the intention of this paper, however, to go into hot runners in detail. At the same time, it would be impossible to discuss tooling advancements within this period without devoting some time and space to this subject. I am, therefore, reproducing examples of various units from my own article on this subject published in 1960 in "Rubber and Plastics Age". These units illustrate the developments that had already been achieved by the mid-50s and 1960 in tooling advancement (Figures 3, 4 and 5).

Two of the early difficulties that we established during development, were seepage of plastics from the nozzle of the hot manifold location into the fixed half of the mold and positive location caused by thermal expansion of metals under variable temperatures. Both conditions tended to be magnified particularly on multi-impression cavities. One of our more successful methods of overcoming both these difficulties is shown in Figure 5.

Relief of heat loss where the nozzle contacts the mold and the hobbing of cavities by direct contact of the nozzle seating are two further distinct advantages achieved by this method. You will note that again the principle of using the plasticized material to form its own insulation was used and lateral float was compensated for by the clearance between the nozzle and the cavity orifice.

Since the earlier periods several developments where a heating device is inserted within the nozzle itself have further helped to improve material flow by the introduction of controlled heat into the nozzle center and away from the outer extremities of the nozzle.

IMPLOSION NOZZLES AND VALVE GATED MOLDS

In conventional molding, plasticized material flows into the mold as soon as injection pressure is applied. Using the precompression system, however, filling of the mold is delayed until full compression pressure is developed. Speed of opening of the valve gate allows a fast decompression of the melt to flow into the cavities at a much higher rate than is normal. Several of these applications on sequential impact molding have patent claims on them.

In principle, however, a valve gated mold is a hot runner unit type construction with the runners leading directly to the cavities forming a gate. A valve pin can move forward and back to shut off this gate or allow material to flow from the runner into the cavity. These pins or rods being controlled by hydraulic or pneumatic cylinders (Figure 7).

During mold opening the valve pin is closed, and injection pressure is raised against this closed valve. On mold closing the hydraulic cylinder is actuated, rapidly opening the valves and allowing the decompressed material to fill the cavity at a very fast rate. Due to the shut-off on the valve pin, this also produces

a clean sprueless part.

If we examine the flow pattern of progressive developments it will now become apparent that tooling advancements are not made overnight but they are, in fact, a series of steps and improvements on basic ideas.

Figure 8 shows a photograph of actual molded parts from hot runner or insulated runner molds now in everyday use within the industry.

Figure 11 shows multi-color moldings using the same modern methods of tooling.

MULTI-COLOR MOLDING

This comprises producing a first shot in one specific color (or alternatively one material) and the second and third shot in other colors (or materials). The first shot is used as a pre-form for insertion into either a second tool or second cavity. A separate press is normally used for each shot or color, with the pre-form or first shot being manually inserted into the second mold (Figure 9). Let us now consider this same sequence as a fully automatic set-up using one press with twin chambers and nozzles and utilizing our hot runner techniques for transferring plasticized material to the pre-form or first shot and also as a feed unit to the second shot.

The part we have to produce could be a plastics beaker with a white porcelain style finish inside and an attractive range of pastel colors on the outside. Our injection machine would have the conventional chamber mounted in the horizontal position and a second unit mounted vertically above the fixed half platen.

Now we have several variables to consider in the design of our tool, but we also have common features that we can also utilize. Let us first then examine the tooling sequence and thus determine what provisions must be made. Our first shot then will inject in unison plasticized material from both chambers. We must first transmit the material through hot runner units into the cavities of both forces. Now our first shot is to be the internal part of the molding and our second shot will be the outside part using a pre-formed internal shot from the first cavity.

Three factors now emerge and we have from these three factors the basis of a mold design.

1. The first and second cavities must be of a different form.

2. The fixed half must remain stationary and the moving half must index with each cycle.

3. Both cores and ejection units must be uniform - ejection units must also either work independently or must clear the first shot as we do not wish to eject the first shot.

Finally, a positive index unit must be fitted to the moving half of the press and the moving part of the mold must be mounted on this unit. We must also provide for knockout rods to actuate the ejection and the index unit must be both rigid and positive. It is essential, therefore, to tie in the index sequence into the press automatic cycle so that only when the index plunger is positively locked in its true position can a signal be sent on to continue the cycle. This is usually accomplished by mounting a micro-switch on the index plunger mechanism, and

incorporating safety cams and interlocks within the unit. With hot manifolds within the fixed half of the mold, we can then increase our original one-cavity first shot and one-cavity second shot into a multi-cavity unit and each complete cycle will now automatically mold a double shot component (Figure 10).

CONCLUSION

On evaluation then, tooling advancement cannot be assessed or measured over the span of one year. Every day technologists within our industry are making forward steps and experiments, but these steps are based on proven facts and known factors. We are constantly as an industry, looking for faster cycles and reduction of secondary and manual operations. A large measure of our success over the past years and our future expansion as an industry, must go to our custom molders. The strong healthy competition within our industry will not allow the existence of outdated ideas to survive.

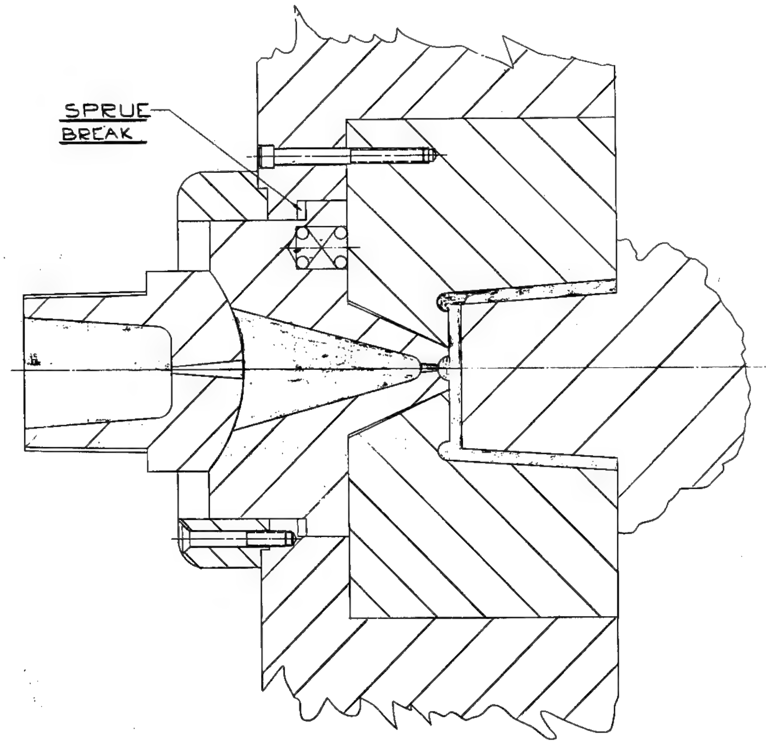

FIGURE 1: Italian Type Sprue

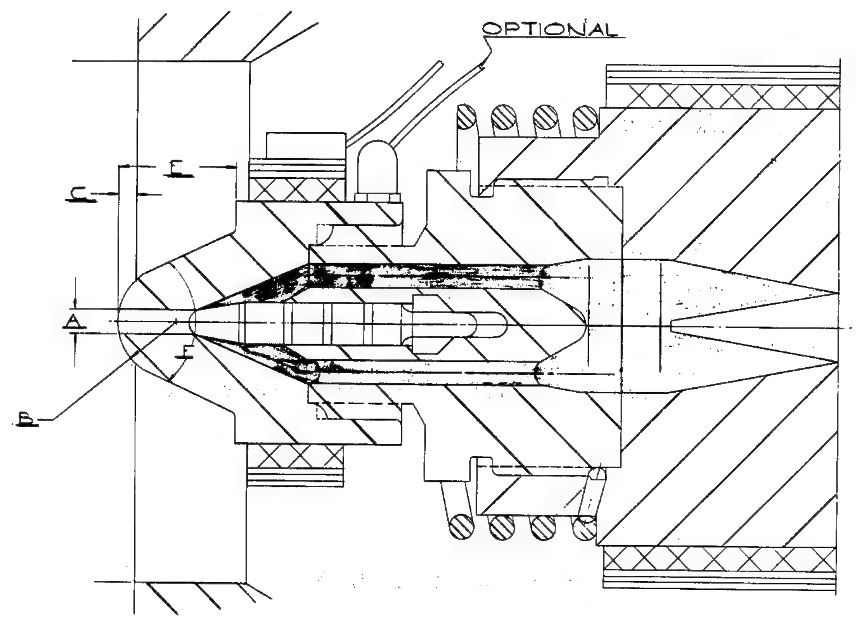

FIGURE 2:
Pressure Operated Needle Valve

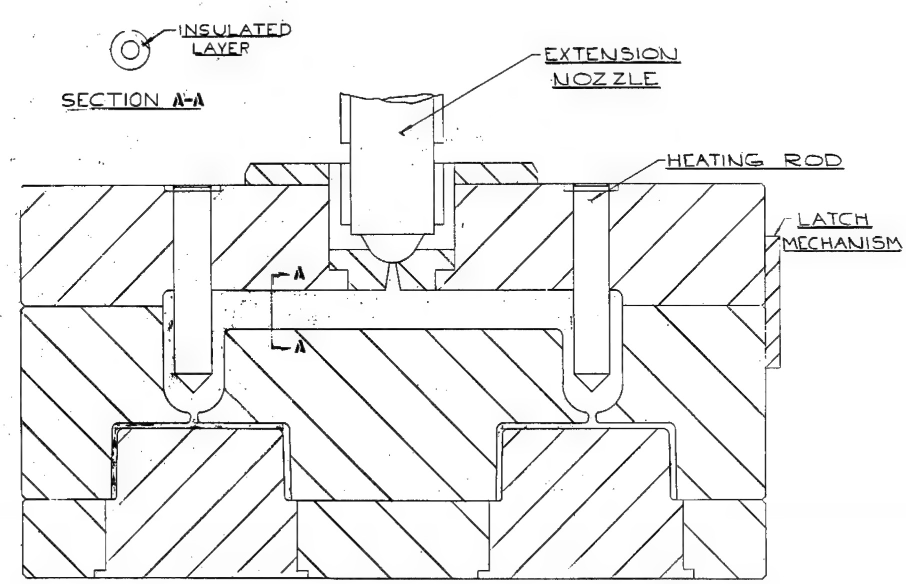

FIGURE 3: Insulated Runners

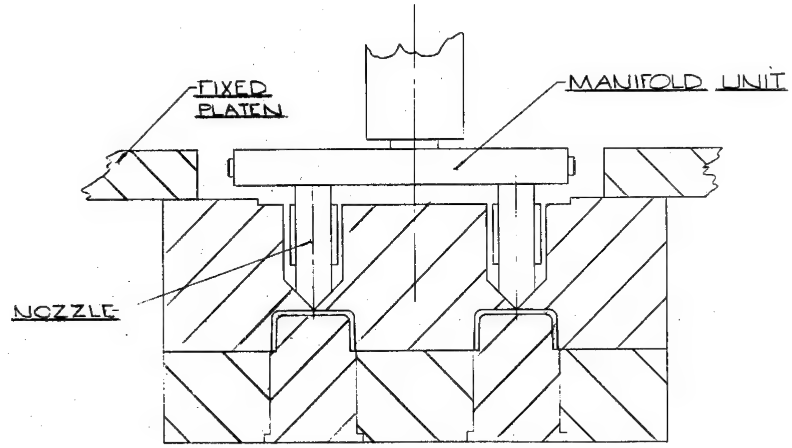

FIGURE 4: Multiple Extension Nozzle

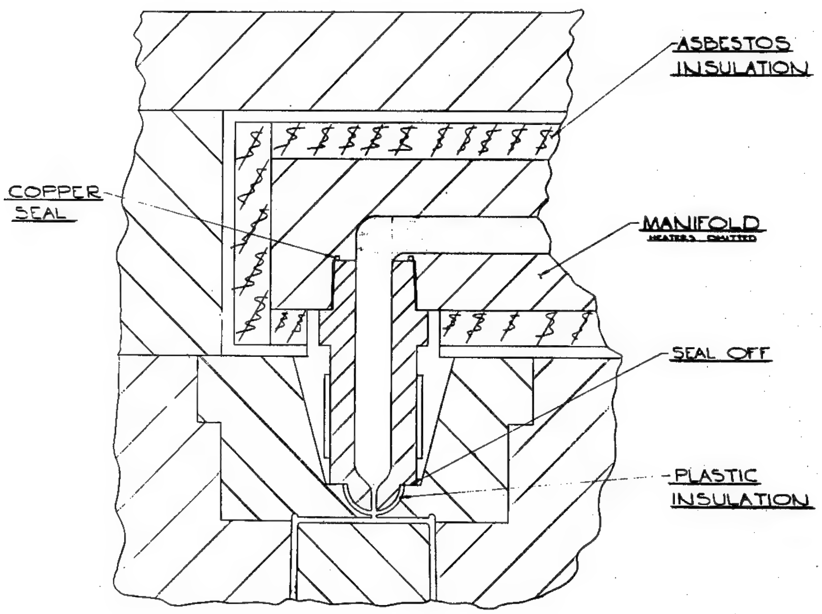

FIGURE 5: Manifold and Nozzle

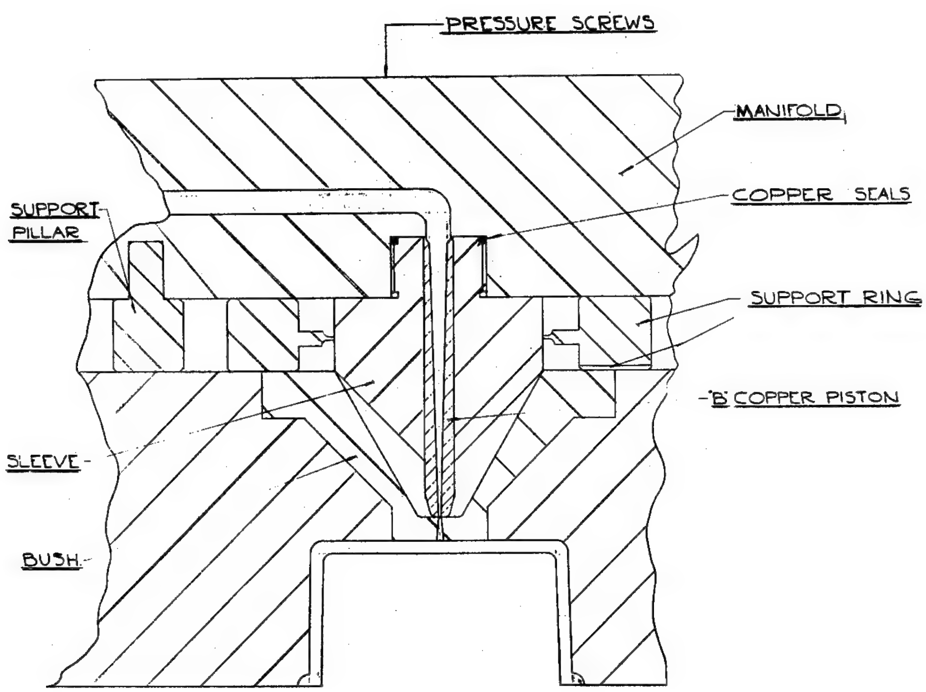

FIGURE 6: Piston Type Nozzle

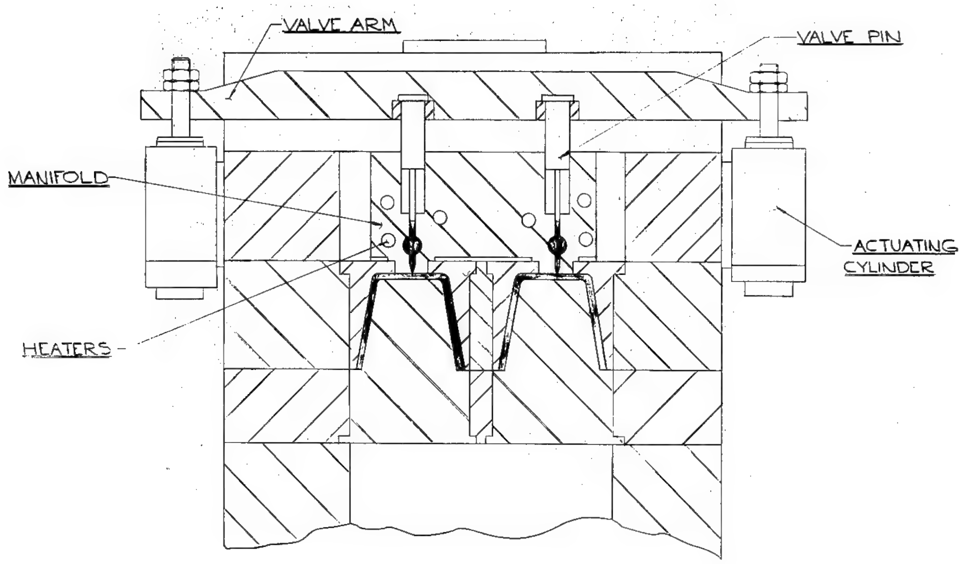

FIGURE 7: Valve Gated Mold

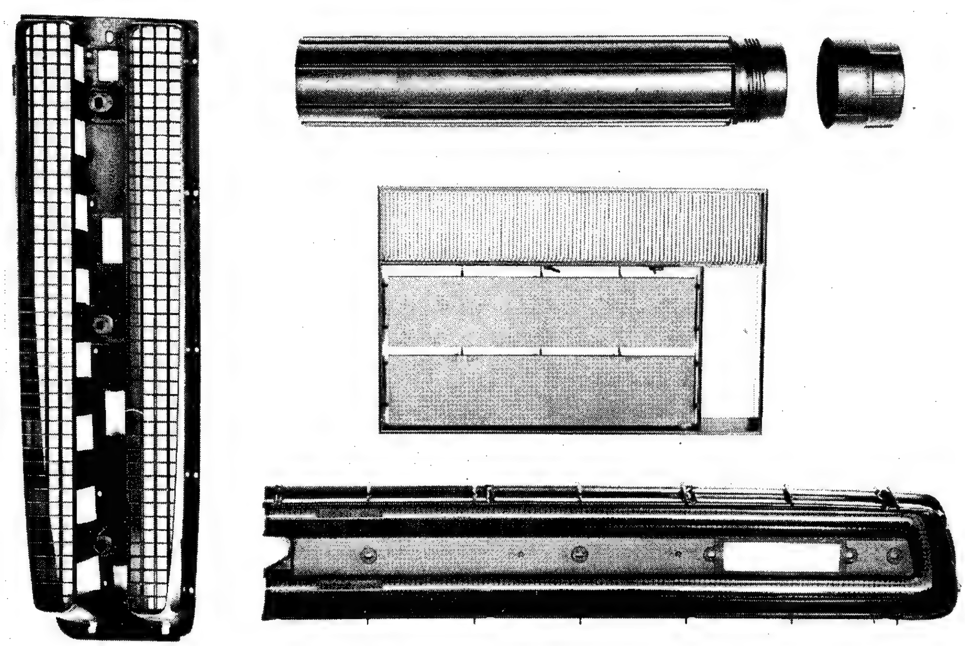

FIGURE 8A: Examples of Hot Runner Moulded Parts

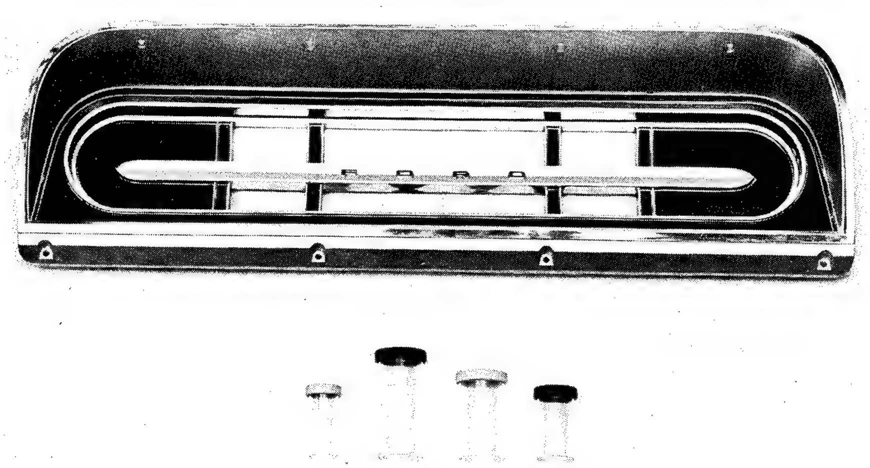

FIGURE 8B: Variable Sized Parts Produced by Hot Runner Moulds

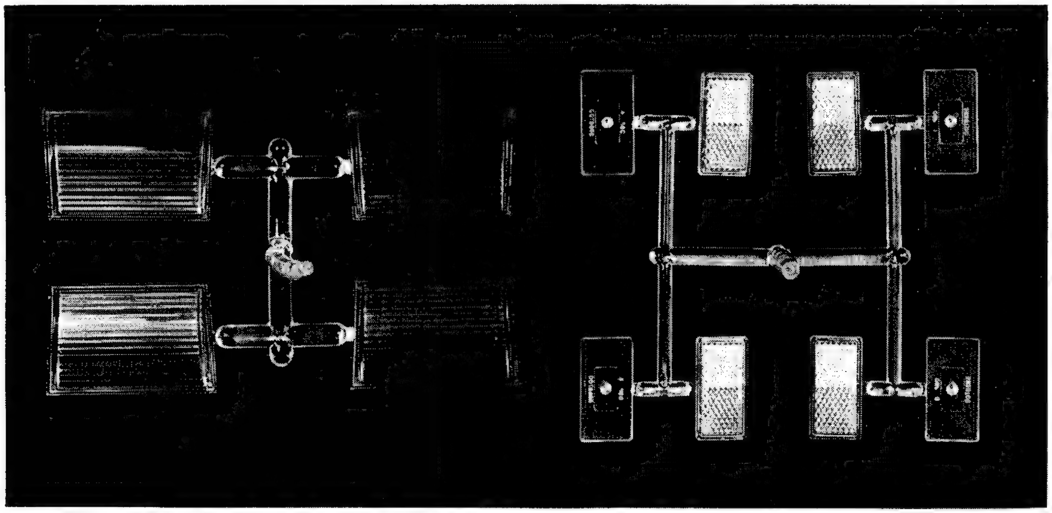

FIGURE 9: Preforms or First Shot Parts

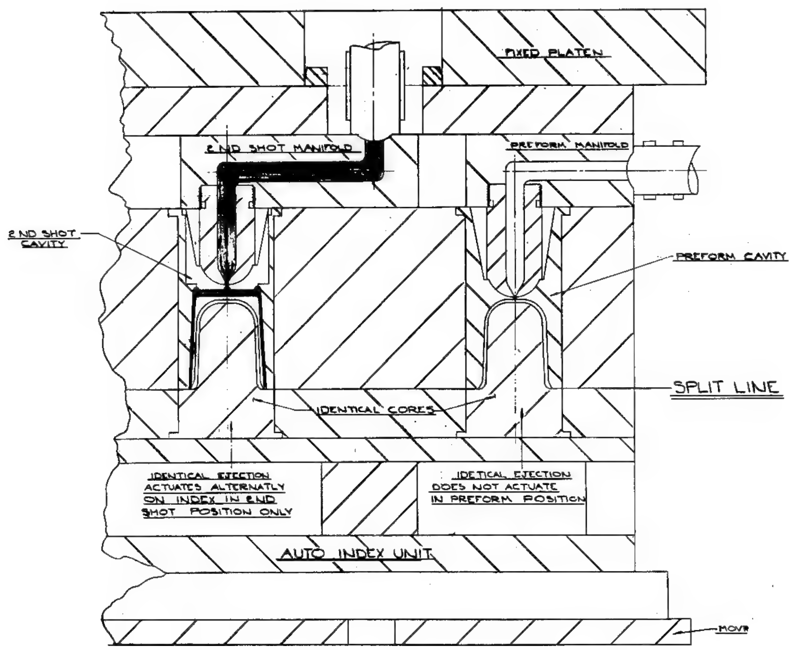

FIGURE 10: Schematic Layout for Multi Colour Moulding using Auto Index Technique

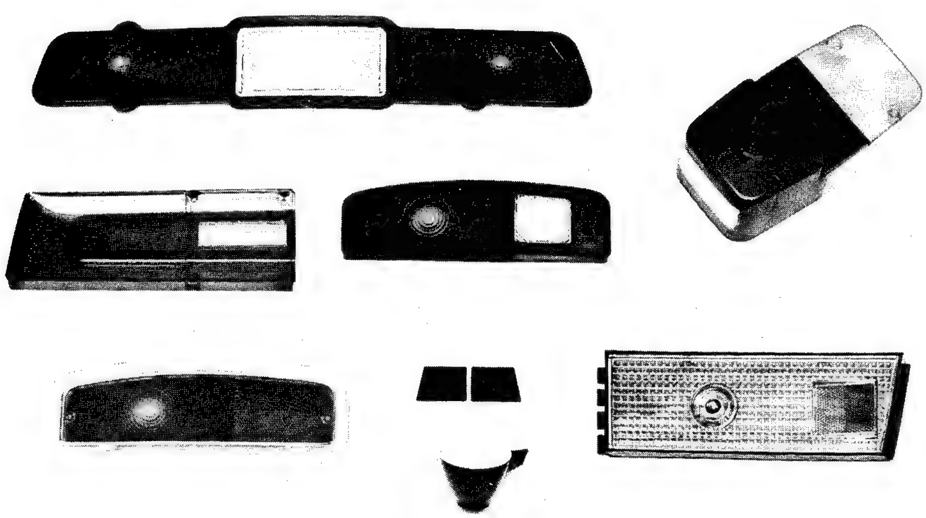

FIGURE 11: Examples of Multi-Color Moldings

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MOLDMAKERS AND A MOLDING MACHINE

436

James R. Driscoll

Injection Mold Sales

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Dayton, Ohio

ABSTRACT

As an added customer service, some mold-making shops are installing a molding machine for try-out purposes. The effects on a moldmaker's business along with the advantages and disadvantages of having a try-out press will be discussed. The acceptance of this service by the custom molder and the captive molder will be presented as will observations made after two years of operating the machine in our plant.

CONSIDER YOUR CUSTOMERS' NEEDS

As plastics assume a greater role in manufacturing, we, as moldmakers, are being forced to keep abreast of new techniques of moldmaking. The advances made in new materials require the moldmaker to make some radical adjustments in his approach to mold design considerations. As more manufacturers install their own molding systems, a further demand will be made on moldmakers' abilities and ingenuity. In view of the future growth of the industry and our interest in our own future, it was our decision to have a molding machine for mold tryout.

Prior to our purchase of a machine, we discussed the feasibility of such a move with our customers. It was met with various reactions from "Yes" to "No" to "You'll be sorry".

CAPTIVE MOLDER'S INSISTENCE ON TRY-OUT OF NEW MOLDS

The captive molder (one who molds and assembles for his own products) was greatly enthusiastic. It is the captive molder's belief that his molding machines are in his plant only to run production and not to sample new molds. This theory is borne out by his quotation requests that specify that the new mold is to be tried out and that 25 to 50 samples from each cavity are to be submitted prior to shipment of the mold to his plant.

CUSTOM MOLDER'S FEARS AND ATTITUDES

The custom molder on the other hand, was only lukewarm. His greatest fear was that after purchasing the machine, we would become custom molders. Many of the custom molders today began as moldmakers. This, I assured them, was not going to

happen to us. We wanted the machine only for the try-out of molds, and if we built better molds as a result of having the machine, everyone would benefit. After our purchase of the machine we initiated a company policy that we would not produce more than 99 shots from any mold after we molded acceptable pieces. If a customer, custom molder or captive molder, requested more samples from a mold than our allotted 99 shots, he would have to pay for removal of the mold and re-installing the mold between each 100 shots. This policy is strictly adhered to and has kept us out of the custom molding business. Needless to say, not many molders want to pay the premium that would be involved in our producing one thousand parts.

A custom molder also schedules mold sampling time in and around his regular production runs. His production requirements, not being as high as the captive molder in most cases, allow him more open time in his presses. This time is allocated for new mold tryout because most mold shops do not have try-out equipment. The custom molder also is hesitant to pay the increased cost of our trying out a mold because the mold cost is usually the deciding factor in which a custom molder is awarded new business.

It has been our experience that the captive molder is well aware of the advantages of mold tryout while the custom molder leans toward a "wait-and-see" attitude.

DISADVANTAGES TO THE MOLDMAKER

While we do not consider ourselves unique in offering mold try-out services to our customers, we do feel that we are qualified to list the disadvantages of having a molding machine in a mold shop. These problems are not necessarily listed in their order of importance, as they each demand considerable prominence as you become aware of them.

A. Press is Idle Most of the Time

As most of us who make molds know, our shops are usually too small. We would all like to have more room for productive equipment. A molding machine in a tool shop is used at most 20 hours a week, and the rest of the time it collects dust. It also represents a considerable investment that is not producing day-in and day-out. This investment and floor space take on great proportions when the machine is empty and management has to keep walking around it. It seems sensible to go out and get a mold to run when the machine is not being used. It may seen sensible, but it is also fatal. The first production run made in that machine alienates all of your custom molding accounts. It may be that the custom molders need more competition, but in our area of the country we do not believe this to be so. The solution to the problem of the machine standing idle is to close your eyes when passing by it, especially if you value your customers.

B. Risk of Damage to Unpaid-for Molds

Another item that will require some thought is that the mold you are trying out is not paid for. The impact of this fact will grow on you as I speak. We, as mold builders, usually ship our new mold over to our customer's plant and then return to our shop. We wait for a 'phone call and if we don't receive a call, we consider no news to be good news. If the molder has an accident with

our new mold, some of the blame can be laid to him, whether justifiably or not. Both the molder and the moldmaker talk over the problem and usually both come away not quite satisfied.

When you as a mold builder install a mold in your press, all of the responsibility for the tool is yours. This could scare most moldmakers right out of the try-out business, but it need not. Our solution to this problem is to place people around the machine to watch that everything is functioning properly. I don't mean to put apprentices around the machine. Put good, experienced moldmakers on the job. In the tryout of over one hundred molds varying in price from $1,500.00 to $35,000.00, we have yet to damage the first one. We believe it is because we are careful in running our tools. We would suggest that you follow about the same sort of procedure.

C. Risk of Losing Moldmakers Due to Their Knowledge

The third disadvantage is one that we just believe to be a possible disadvantage. We don't know for sure that it's going to be. Many mold shop owners are reluctant to send their best men out to a molding shop or to a captive organization to work on molds due to the fact that these people can, by their knowledge, be stolen from them or recruited or whatever the ethical term might be. This is a gamble you take. This is where one of the disadvantages comes into play. The disadvantage is that on all molds that we make in our shop, the lead moldmaker is over at that press when the mold is put into the press. He stands there with the operator, watches everything going on, and we are taking a gamble that we are raising a breed of intelligent moldmakers who happen to know how a molding machine functions. Some of you sitting here as mold shop owners probably have working in your shop some pretty good men who don't even know how a molding machine works. By having a competent moldmaker installing a mold into the machine, the mistakes that he makes such as having a water line connection interfere with a tie-bar, usually happen only once. He knows how much trouble it is to pull the mold out and make these adjustments. The disadvantage then lies with the fact that we're getting some pretty smart men in our business. Some of our men might leave us and start mold shops. They know from their own experience the service that we are giving our customers. If they leave us and go into business, we're going to have some pretty good competition, people that know what it takes to build a quality mold and also how much effort we put into the mold. It wouldn't hurt the mold making industry at all if we had competition like this. If we lose people by this route, the customers they'll work for will probably be people we are doing business with right now; and we believe their molds will reflect this extra care that we've taught them to build into a mold initially.

D. Additional Cost to Molders for This Service

Also to be included in any list of reasons for not having a try-out machine, is the fact that the mold price is higher. The cost for try-out is a service that a moldmaker provides. This cost is borne by the molder and is added to the mold cost. Some molds can be sampled in three hours, others may take three days. It has not been our experience to lose the building of a new mold because our try-out was too expensive.

Therefore, the disadvantages in our opinion are these - there is a considerable investment not working to full capacity, the molds are not paid for prior to your tryout, the risk that your employees are better trained and you might lose them, and the mold cost increases for the service.

ADVANTAGES OF HAVING THE MACHINE

The advantages were saved until last because again, in our opinion, we believe them to be so great as to offset any disadvantages. They are not listed in their order of importance due to their being so much dependent on each other.

A. Cover-up of Mistakes

One of the greatest benefits realized is that you cover up your mistakes. When plastics enters a mold cavity it tells few lies. If you forgot an ejector pin, it shows on the part and also in the ejector housing, and sometimes even on the floor. We have forgotten ejector pins but our customers don't know it. Once we forgot the gate. Another time we put the sprue bushing in too deep. Before we determined this to be the problem, we were ready to overhaul the injection cylinder. These mistakes, while comical to relate, get few laughs from your customer. Especially when they occur at two o'clock in the morning and the end user needs the samples by noon. Seriously though, when a moldmaker sees the first shots from a mold, he can make adjustments in an efficient manner; and usually the molder will produce an acceptable part when he gets the mold. Most minor corrections that the molder will need can be made in his own plant.

B. Ground Floor on New Projects

The availability of an idle molding machine in a mold shop draws captive molders to your doorstep. A good percentage of parts designed in plastics are never built due to the problem of obtaining temporary tools at a reasonable cost and delivery. The captive molder, his machines being kept busy for his production requirements, usually has custom molders supplying his short-run needs. When the end user needs 30 parts to test the feasibility of an idea, he must go to a custom molder who in turn goes to a moldmaker for the temporary mold. This raises the cost of the parts and the mold because of the follow-up that is necessary. The custom molder also runs the risk that if the part is satisfactory he might not run the production. This then causes the custom molder not to get too interested in prototype work. This does not answer the need for the end user though, and this is where the moldmaker with the machine comes in to view. Having the machine open most of the time allows your captive molders to come directly to you for prototype molds. Some of these parts will fail in testing, others will become production items. When a part goes production and you have prototyped it, who would the captive molder go to for his tool requirements? Provided your price and delivery are within their guidelines, you are going to get the production molds. I will give you an example of one such program. A large appliance manufacturer with molding facilities contracted with us to build five experimental molds. The parts were for one assembly and after 18 months of changing and revamping, the parts

proved successful. We were awarded complete tooling on the project with the volume requiring two complete sets of four-cavity molds. This is good business, and I am sure was based on our complete familiarity with the part from its inception.

In order to expedite our orders for prototype work, we have experimental mold frames into which we insert our temporary cavities. One such mold base has produced 32 parts with only sprue bushing and ejector plate replacements. The cavities are sometimes cut into aluminum, sometimes steel or brass; and on a few applications we have cast them in epoxy. The methods used for prototyping are usually determined by the geometry of the part.

C. Improved Mold Designs and Molds

A large proportion of the molds that we build are single-cavity molds in multiple-cavity frames. This allows us to determine mold base size, runner and gate location, and also arrive at a definite shrink factor. In all cases where tight tolerances are required we leave the mold cavity heavy in order to remachine the steel after inspection of the part. This is of greatest importance when tooling for materials with high shrink factors. When designing a single-cavity mold in a multiple-cavity frame, we also are able to under-design due to the fact that we can try the mold out. Our method of design is to draw the mold with minimum ejection leaving the way clear to provide more if it is needed. Our discussions prior to the designing of a mold usually center around what can be done if simplicity doesn't work. A perfect mold in our estimation, has no moving parts. Of course, we cannot achieve this, but we keep trying.

We have learned by working with the press that many molded pieces are over ejected. We have also learned how effective air ejection is in some cases. Prior to our having a molding machine, we used conventional knock-out systems with air assists on closed parts, such as ice cube containers. Now, we build molds with just the air valves, confident that the part can be ejected by this means. Without the machine, we were never quite sure that satisfactory results would be obtained.

We have concluded that the molding machine and the experience we have gained from it allows us a flexibility of mold design that we were not accustomed to and definitely aids in building better molds.

C. Savings of Time and Money by Try-out

Of the advantages we have discussed, we will have to add this last and possibly the greatest benefit of all. This is the saving of time and money by try-out. This money is saved by both you as the moldmaker and your customers the molders.

Mold shops without try-out equipment now build a mold, ship it by truck to the molder and wait for him to try it out. If trucking firms are involved, it might mean a waiting period of two days before the molder sees the mold. He must then schedule the sampling in among his production runs and this can involve a few days. When he finally gets the mold in a press, the part produced may not be

exactly as the print. I say may not because once we shipped a mold that didn't need any corrections. It was a single-cavity mold for a color chip. Usually though, the mold must be vented or more polishing is required or some trivial adjustment that requires the mold to be returned to the moldmaker. Three days later the mold returns to the shop and meanwhile your shop people are working on another project. They must then stop the new job and try to remember how they built the last one. The corrections must not only be made, but the tool must be shipped again and then re-sampled. All of this takes time and it is entirely non-productive except for the transportation company. Our method is to install the mold in the press as soon as it is assembled. The moldmaker has all of his tools out for the assembly and the job is still fresh in his mind. If vents are needed, the mold is pulled and the vents are added in a workmanlike manner, not with a hand grinder inside the press like many of us have tried to do. If hangers are required, they are installed by a machine and not by hand. These adjustments are made and the mold is shipped on its promised delivery date. The economies affected by having a molding machine in this instance alone will pay for a press in a very short time.

The advantages then are these - you catch your own mistakes, you gain an inside track on new projects, the design and the building of your molds improve, and you save both the customer and yourself considerable time and money in trying out new molds at your own convenience.

OPERATION OF PRESS

The operating of the press presents some problems that need considering. The selection of a suitable person to run the machine is difficult in that the machine is used at any hour of the day or night and you must have someone willing to work under such conditions. We started with one of our better moldmakers in charge of the try-out and this proved satisfactory, although expensive. We were then able to employ a man who worked for a molder as a set-up man, but who wanted to learn moldmaking. This proved highly successful from the standpoint that when the press was not being used, this person could help with the building of the molds. Another observation that we made was, as moldmakers we were prone to remove the mold from the press before we gave the new mold a chance to prove itself. Having a person with prior molding experience running the machine allows him to try many of the variables in molding and also recommend the changes to the mold that will best improve its performance. A molder's judgment of what a molding machine should do and what a mold should do is, in our opinion, better than ours. If it is at all possible to employ someone with molding experience, we believe that your try-outs will be more successful.

A. Auxiliary Equipment

Along with the purchase of a machine, some auxiliary equipment will be required. The addition of a water temperature control is of the greatest value. With a temperature control unit you are able to get the mold up to operating heat faster without making shot after shot waiting for the mold to settle down. This involves a real saving of both time and money when you have moldmakers at the press. In many instances, we have found that temperature control can be the difference between a good mold and one that is so-so.

Another item that was necessary for us was additional pyrometers. Being quite expensive in hot runner molds, we found that we needed additional control for heating the blocks. We bought two pyrometers and mounted them permanently to the machine. This saves us money in that while we are installing water lines and adjusting the press, the hot runner block is coming up to heat. As our molds are assembled, they are wired up and plugged in common outlets at the machine. We also use powerstats when necessary for single-nozzle control. This item, while necessary to us, may not be of much importance if your requirements are different.

A material dryer is alsouseful, especially if you are molding nylon. The dryer should be of good quality and of sufficient size to handle your molding requirements. A hopper dryer has not been of any advantage to us because of the small number of pieces that we mold.

B. Materials, Cost and Storage

Molding materials offer no unusual problems other than proper storage and some method of determining what you have. We have found that if you have ten pounds of material after a try-out, it is best to throw it away. Otherwise, you'll collect so much it is impossible to keep track of it. There has not been any cost to us for material as it is supplied by the molder for the specific job. The materials people have always been more than willing to send us all the resin we need as this puts them in good standing with their customers. It also gives them a free laboratory service for only the cost of the material. This can be a disadvantage from the standpoint that a molder might want his mold tried out in four or five materials. When this happens, it becomes necessary to discuss this problem and work out a solution.

The type of machine that you purchase should be relative to the size of the molds that you build. Our machine is a 16 oz. Watson-Stillman and about half of our molds can be run in this size press. The other portion of our business is in large molds of the television and air conditioner front size. To try out molds of this size would require quite an investment; but as the demand for larger size molds increases, we will certainly look at the economies involved in acquiring a large machine.

CONCLUSION

In conclusion, we would like to caution you as to the exact function of a molding machine in your shop. Its purpose should be to prove the functional workings of a mold. The fact that the part as produced on your machine does not meet all of the dimensional tolerances is of little consequence. Your molder's ability to give you a shrink factor to build the mold to is a result of his experience with his own equipment, and his knowledge of materials. It is only his ability that allows him to exist in such a competitive market. Take the molder's advice as often as he will offer it because it usually works. The same applies to the technical people in the materials field. This is their business, and it behooves them to have their product behave properly. The addition of a press to your plant will give you more respect for the molding industry.

It has been the intention of this paper to present to you our experiences in this field of customer service. It is our desire that more moldmakers enter this area. We feel that the competitive picture of moldmaking will improve as more of us become cognizant of molders' problems. It is also our desire to improve the art of moldmaking and to have mold-building techniques keep abreast of new materials and new molding machines. Your abilities as moldmakers are vital to the future of plastics, and will most certainly be welcomed by the industry.

9579-3

MOLD DESIGN FOR HIGH SPEED PRODUCTION OF DISPOSABLES

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INTRODUCTION

The plastics disposable market has grown at an accelerated pace during the last decade, especially in such markets as food containers, and in hospital and medical supplies. This development may be directly related to the fact that the molding industry has moved out of an experimental era which has made a considerable increase in plastics disposables possible. Injection molding machines have matured to a state where their performance has become reliable and where with the technological knowledge of today they can be built for any given application.

Today's output of machines is not anymore governed by the machine itself, but by tooling and secondary operations. In the future, therefore, we can look for most technological achievements to be made in this field.

In this paper, I would like to discuss the problems encountered in design of tooling for disposables and the probable solutions. Also since the disposable market relies on the whims of the consumer, I would like to discuss a production method of molds which can meet the required shorter delivery dates.

COST OF PRODUCTION AND INVESTMENT PER PIECE

In order to keep the price of a disposable item on an economical level, a high rate of production has to be achieved. At first glance, the very obvious way of doing this would be to have a large number of cavities designed into the mold. Undoubtedly this will give a high production rate for a given cycling speed. However, this speed is greatly influenced by the capability of the mold to recycle. The more impressions designed into the mold, the more difficult it is to cool. If a hot-runner is used, the control of gate temperatures will cause problems. The maintenance of the mold, of course, will be high, so will be the cost of it. When downtime occurs, production loss will be considerable, and above all such a mold would require a large machine, which means a big initial investment.

Due to the already mentioned difficulties in hot-runnering such a mold, the designer will possibly favour a runner type mold, which in many cases will require an operator, and this again will offset the cost advantages gained by the larger number of cavities.

The other alternative, of course, is a small machine with a mold containing fewer impressions. While the saving on the initial cost of such equipment is obvious, there are several other advantages to it. Due to simplicity in mold

construction, the mold can be cooled better; consequently, higher running speeds can be obtained. It is a relatively easy task to build and effectively control a hot-runner system for a few cavities. Maintenance cost and product loss in down-time is lower. In case of very thin wall containers, a machine can be built with twin nozzle injection. This machine would take two small molds (1 to 4 cavities). While the two molds are in constant operation, a third one may be on the shelf and breakdowns would only take as long as a set-up change. Furthermore, the faulty third mold would be repaired while the other two are in operation. Naturally this kind of set-up requires precision in machine and especially mold building.

The obvious conclusion from the above is that properly built high speed equipment with molds having small numbers of cavities will not only be a cheaper capital investment, but will also outproduce the large equipment, thereby being more competitive on the disposable market.

COST OF MATERIAL PER PIECE

To keep the production cost of a disposable item down, however, is only part of the problem. An equally important factor is to keep the material cost of the part as low as possible. Limitations in the thinness of parts leads us to the question whether a runner type or runnerless type mold should be used.

The advantages of a runner type mold are obvious. It is cheap and simple to construct. These, however, are offset by the waste of the runner, the problem of separation, the cleanliness of regrinding, and, above all, by the extended cycle time required to cool the generally heavy section of the runner and the sprue. While it may only take fractions of a second to cool the part with a wall section of .025", it will take at least two seconds or even more to cool the 1/4 dia. runner that fills the part.

The runnerless mold, on the other hand, possesses several advantages. Since there is no side product, there is neither waste, nor reproducible scrap (no regrinding). There is no problem of separation or screening and, naturally, cooling time is only as long as is required for the ejection of the part.

Considering the above factors, then we may decide to design a runnerless mold with few cavities for a disposable item.

DESIGN CONSIDERATIONS FOR TYPE OF MOLDING

Runnerless systems may be broken down to two basic types - the hot runner and the insulated runner. Figure 1 illustrates a typical Husky hot runner, designed for a single-cavity container mold.

Figure 2 shows a multiple-cavity version of the same system.

Note that in both cases a so-called heater body encases the Becu nozzle tip, through which the melt is being fed into the gate. The heat is being transferred through this tip which at the same time controls the temperature of the gate. The surrounding area of the tip is filled with plastics which serves as an insulator. The great advantage of a hot runner mold is that the mold can be restarted after any length of shut-down without removing plastics out of runners.

Since a relatively large backing has been removed from behind the cavity, it becomes imperative that support is provided by pillars or some other means.

Figure 3 shows a typical design for this type of hot runnering. Gate and tip diameters as well as the position of the tip are dependent upon factors, such as molded material, thickness of molded item and speed of molding.

Figure 4 shows a lid with insulated runner system. It is generally known that this system is based on the capability of the plastics to insulate itself from the ambient cold plates and still maintain a hot core inside, provided this inner hot core is replaced in relatively frequent intervals.

Figure 5 clearly illustrates the separation between the hot core and the cold outside layer.

In order to enable the insulated runner to run on slower cycling speed, and to provide a more accurate temperature control at the gate, heated probes are introduced, as shown in Figure 6. These are torpedoes holding cartridge heaters that are either connected to the heat control through a common bus bar, or are individually connected to separate variacs. The latter method provides a better gate control.

Figure 7 shows a typical gate design, dimensions again being dependent upon factors mentioned in hot runner design.

The advantage of the insulated runner system lies mainly in its simplicity and strength. Its disadvantage is that with every shut-down, the solidified runner must be removed and, of course, start-up is more critical and difficult than start-up of the hot runner mold. Since disposables are molded mainly on 24-hours-a-day operation, the time lost, however, in shut-downs becomes negligible.

DESIGN CONSIDERATIONS FOR HIGH SPEED MOLDS

A. Cooling

Once the selection of runnerless type molds has been made, there are still other factors which affect the speed of the mold, such as cooling.

Figure 8 illustrates the importance of cooling in a breakdown of several molding cycles.

The obvious conclusion from this chart is that the greatest part of the cycle is taken up by cooling the injected polymer. Consequently, this is the part of the cycle where possible time savings become important. Disposables are generally thin walled items, and the time required for the heat to travel to the mold steel is negligible. Important is the time for heat transfer through the steel into the coolant. To reduce this time, the distance for the heat to travel must be minimized. The coolant has to flow as close to the molding surface as possible. The general limitation here, of course, is strength of the mold.

It is also very important that the cooling be distributed according to the needs of a part (more cooling is provided to thick sections, gates and ribs).

Figure 9 demonstrates how the incoming cold water strikes the gate area first, then washing the corners, moves down along the walls of the cup. This careful distribution of the cooling also plays a great role in warpage control. An uneven cooling can result in potato-chip-like distortion of even small lids.

As the fast cycle molding of a disposable item carries a great amount of heat into the mold, it is imperative that this heat be carried away from it. For this reason the pressure on the cooling system is extremely important and consequently the volume of coolant pumped through the mold. In multiple-cavity molds an elaborate cooling system may have to be designed in order that the temperature of all cores and cavities be identical. As previously discussed, this gets more difficult as the number of impressions in the mold increases.

For proper temperature control it is essential to have a closed circuit cooling system.

Figure 10 shows a central chiller unit in Husky's Test Lab.

B. Venting of the Mold

Previously, the problem of cooling would arise, as the mold cavity has to be filled thoroughly with the polymer in the shortest possible time. On cycling the system, we discover a generally overlooked factor in high speed molding, namely, air escape or venting. The amount of the venting is just as important as is its location and spacing. As generally accepted, "some" venting should be put at the end of the filling. But since a disposable item runs on a cold mold, it has to fill fast, and air escapes should be provided in the mold in all possible locations. On such fast operation, spot venting should be replaced by continuous or ring venting, especially on the parting line. While it is true that burning indicates lack of venting, lack of burning does not necessarily indicate adequate venting. Therefore, although the amount of the venting clearance will vary from material to material, it should always be close to the maximum permissible. It has been found that while no burning of the part occurred, increased venting has decreased the cycle from 5 to 4 seconds on a 3-cavity cocktail glass mold. For general purpose styrene containers, we suggest to use .0007 - .0008" clearance. A somewhat less amount would apply to polyethylenes. Polypropylene and allomer, of course, are more critical, and for ring venting the suggested clearance should be .0003 - .0004". The length of the vent should be approximately .070 - .120, running into an open flash groove.

Figure 11 illustrates the difference between spot and ring venting.

To establish the exact amount of vent clearance on a large mold's ring, venting may require some experimenting. The .100" wide venting ring of a 5.000" diameter container for example that runs into a 5/16" wide flash groove may collapse under the clamping pressure as much as .0005" and an initial .0008" vent might become inadequate under operating conditions.

Wherever possible, vents should always be moving and self-cleaning. This applies especially for polypropylene molding, where the moving vent is almost a necessity, as the paraffin blocks up the solid vents in a very short time.

Once the cavities are filled thoroughly and the part has been cooled-off to sufficient stiffness, ejection will take place. The part may have solidified and has taken up the shape of the cavity, yet it may

be soft enough to yield under the pressure of the ejector pin. Great care should be exercised in the selection of ejecting surfaces. Wherever possible, the part should be pushed off the core from the rear instead of being pulled by ejector pins, striking the inside bottom surface. Ejector pins inside of the part can also obstruct the free falling of the part, unless air blow-off is provided. While it is very conventional to eject round parts by stripper rings, this same approach should be attempted even on parts that are square, rectangular or irregular in shape. A stripper plate mold generally is stronger since the core supporting section is not weakened by cutouts for the ejector plates. The cost involved in machining and fitting an intricate stripper ring is not more than the cost for making the ejector mechanism and boring the pin holes. Stripper plates also improve venting and flash control. One of the most important advantages of a stripper plate against ejector pins lies in cooling. Ejector pins running through a core will greatly reduce the possibility of water channeling, which is imperative in a high speed mold for previously mentioned reasons.

As the part is being pushed off, it shrinks tightly on the core, thereby preventing the air from getting behind it and creates a vacuum. Often the thin wall of the disposable part is not strong enough to resist the atmospheric pressure and will crack.

Figure 12 shows a container cracked due to the lack of air release.

On relatively small parts, especially parts molded of polyolefins, a proper surface finish, such as sandblast or liquid hone, will provide enough air release. For very high speeds it is imperative that a positive air supply be provided. Not only is this essential on the core side for ejection, but on the cavity side as well to provide fast release. These air escapes can also be utilized as vents during injection.

Figure 13 is a typical container mold, showing stationary air pin which supplies compressed air at ejection.

Figure 14 shows a similar solution with moving air pin.

In order to insure the part's staying on the core, an undercut is provided. As the part starts moving off the core, the undercut will pry the surfaces apart, and if this undercut is interrupted, the air will seep through the interruptions. This solution is suggested for brittle materials, such as general purpose clear styrene parts, where the mark of an air pin would not be tolerable.

STRENGTH OF THE MOLD

The strength of the mold is always important in any molding operation. An average multiple-cavity container mold weighs around 8-900 lbs. The energy required to move this mass plus the mass of other moving items increases the square of the velocity. The deceleration of the mass subjects the mold to enormous loads. This and the clamping pressure required to keep the mold closed and the fatigue factor due the frequent application and release of the injection pressure, explain why only three cavities were designed into the mold, when four cavities would have filled the layout. This reasoning led us to the decision regarding the

number of cavities.

One more point about disposable molding. Not only is it required that a disposable item be molded economically, today's competitive market also requires fast mold deliveries. The idea that was born today must be sold on the market tomorrow. To achieve this, the moldmaker must be ready to produce high quality, production-proven molds in the shortest possible time. To satisfy this condition, Husky has introduced a standard mold production system whereby a mold for a part that fits within the dimensions of a standard overall design can be produced in a minimum of time, utilizing standard components from stock. Special design is only required for details affected by the configuration of the molded part. Quite often a detail for which special design is required is available in semi-machined form.

Other standards include multiple-cavity container molds, lid molds, screw cap and closure molds.

Since standard designs evolved through years of experience in mold making and only proven details are used, a mold built to standards such as Husky's, has several advantages:

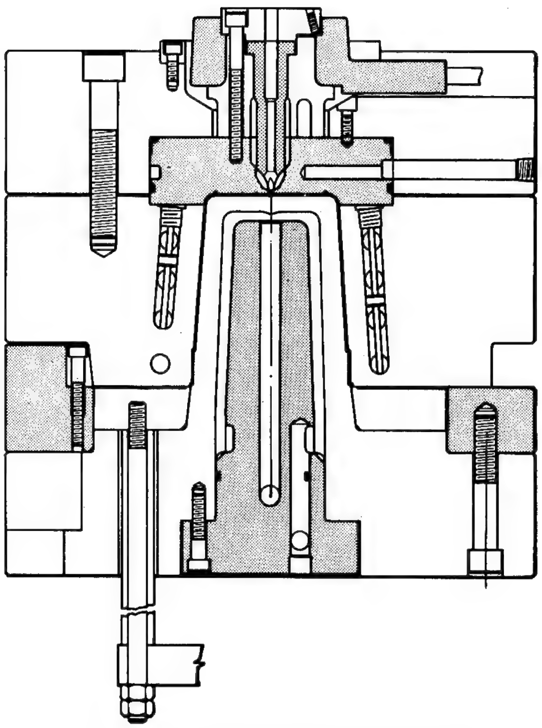
1. It requires little debugging.

2. Performance can be predicted.

3. The design can be chosen from a standard mold catalogue.

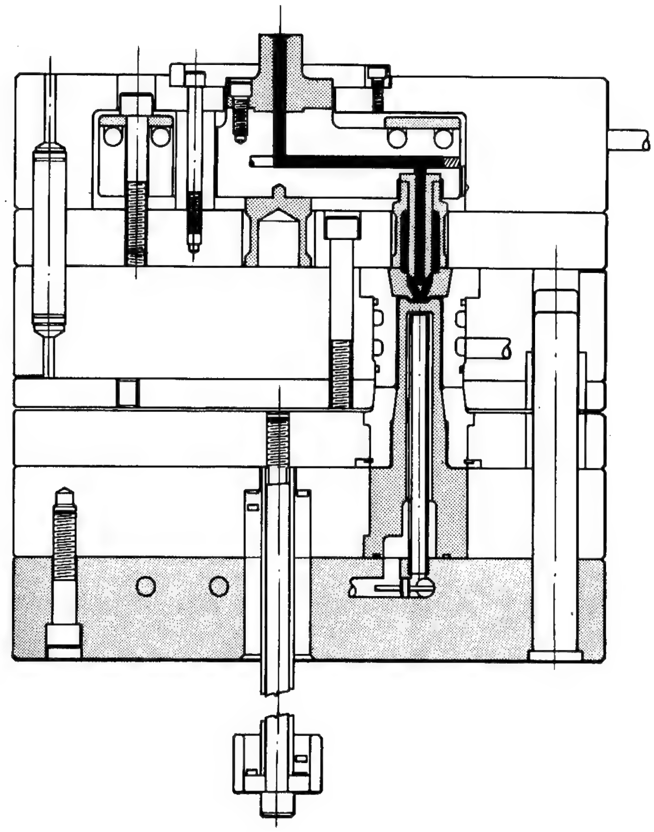
4. Minimum of time is required to build the mold.

Figure 15 shows an assortment of standard mold components.



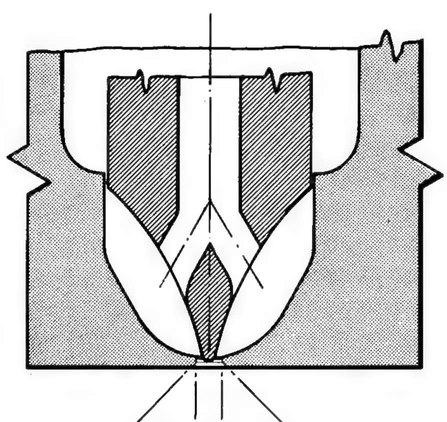
SINGLE CAVITY HOT RUNNER MOLD

FIGURE 1



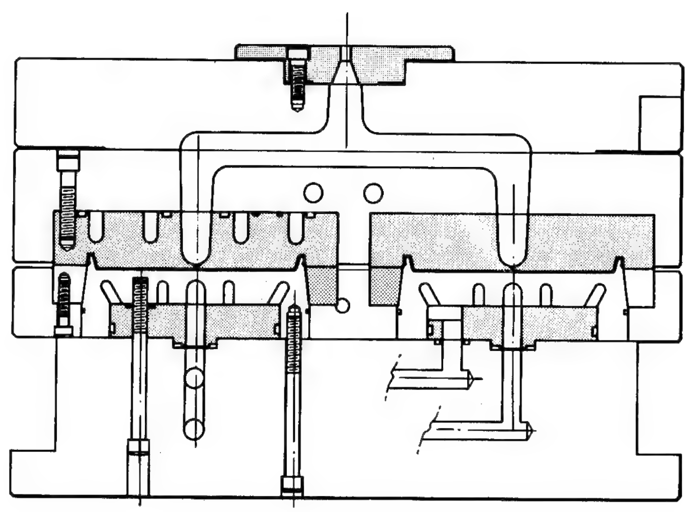
MULTIPLE CAVITY HOT RUNNER MOLD

FIGURE 2



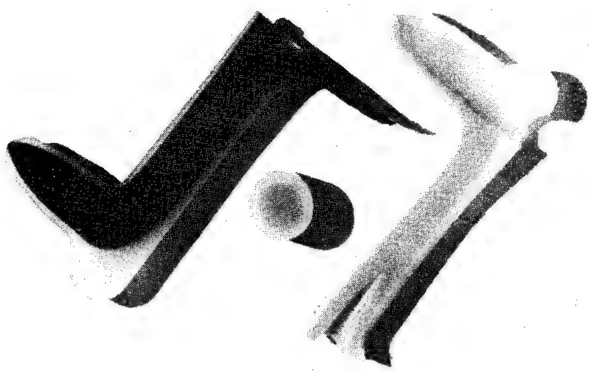
TYPICAL HOT RUNNER GATE

FIGURE 3



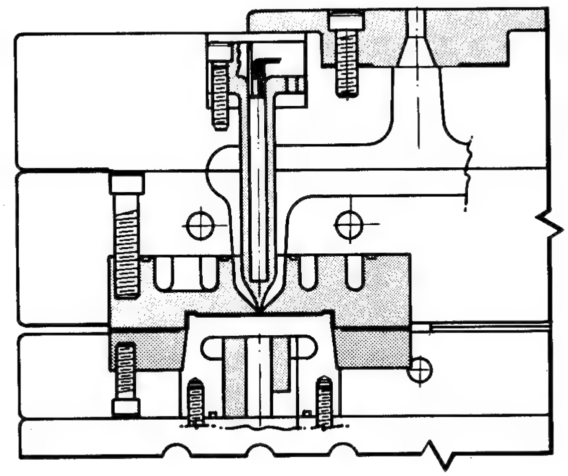
TYPICAL INSULATED RUNNER MOLD

FIGURE 4



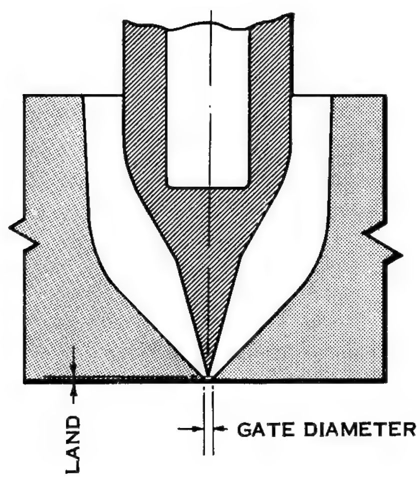
INSULATED RUNNERS

FIGURE 5



INSULATED RUNNER MOLD WITH HEATER

FIGURE 6



TYPICAL INSULATED RUNNER GATE

FIGURE 7

PART	CLAMP OPEN AND CLOSE	INJECTION AND HOLD	COOL	EJECTION AND BLOW OFF	TOTAL CYCLE	COOLING TIME % OF TOTAL
1	0.6	0.5	1.9	1.0	4.0	47.5
2	0.5	0.5	1.3	1.0	3.3	39.5
3	1.7	4.7	11.5	3.5	21.4	53.8
4	1.0	0.7	1.3	1.2	4.2	32.5

BREAKDOWN OF MOLDING CYCLES

FIGURE 8

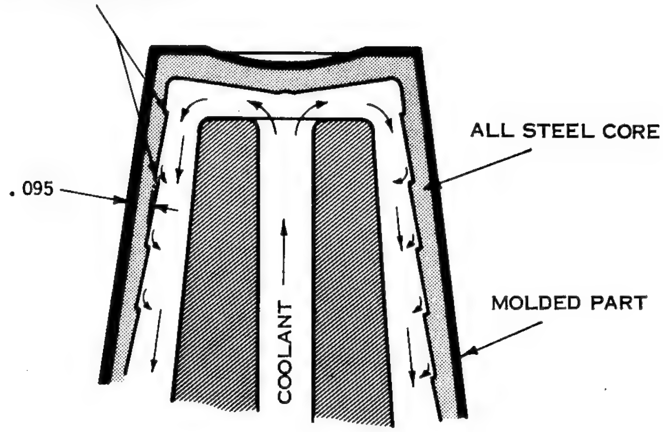


FIGURE 9

COOLANT FLOW IN CORE

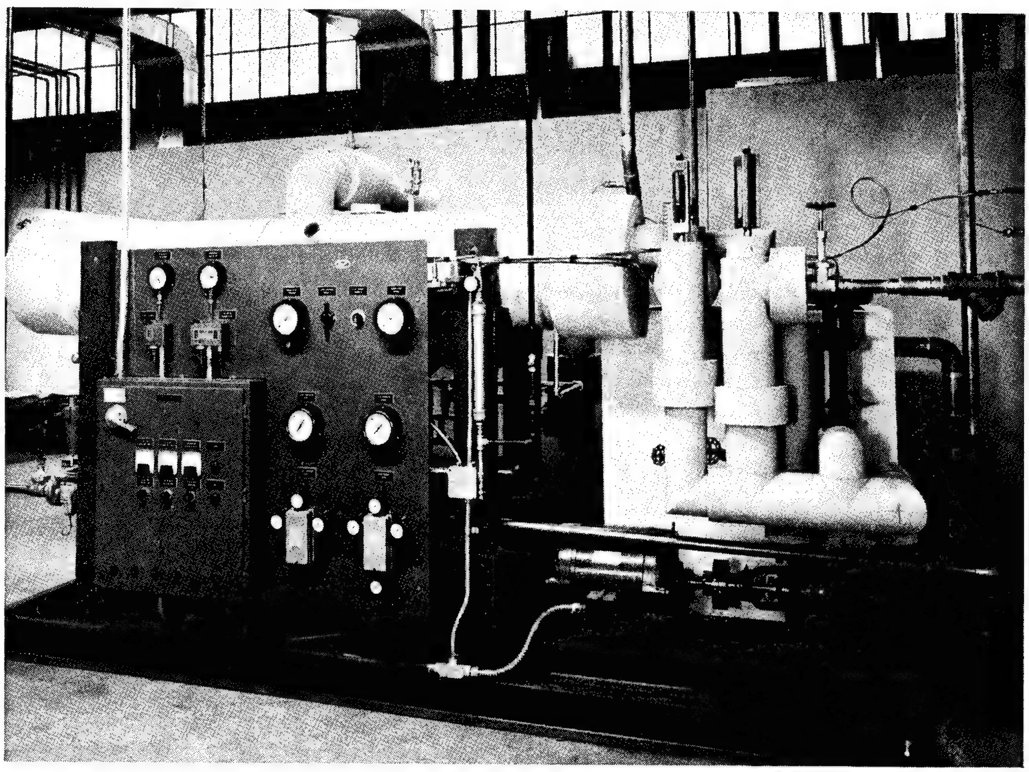


FIGURE 10

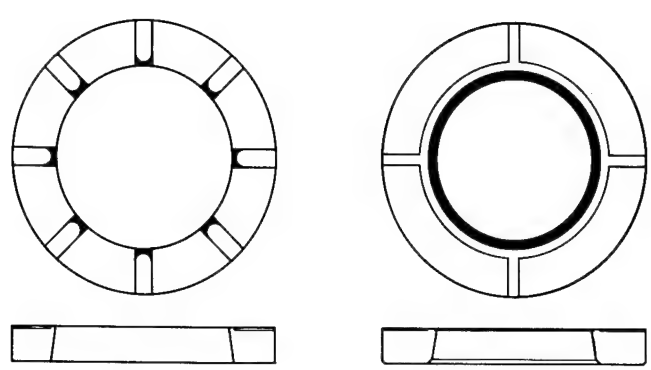
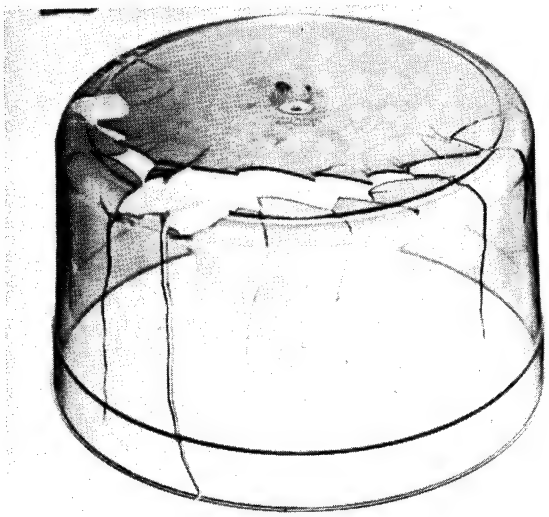


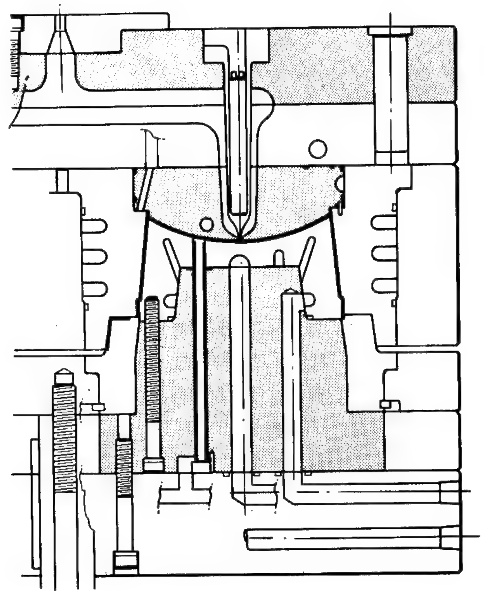
FIGURE 11

COMPARISON OF SPOT AND RING VENTING



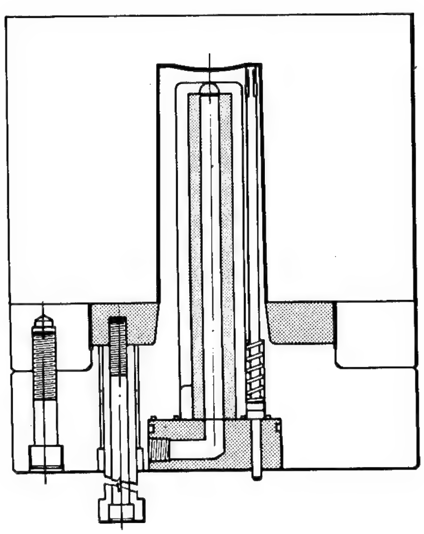
RESULT OF LACK OF AIR RELEASE

FIGURE 12



CONTAINER MOLD WITH AIR RELEASE

FIGURE 13



AIR RELEASE WITH MOVING PIN

FIGURE 14

FIGURE 15

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A COLLAPSIBLE CORE

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INTRODUCTION

A core which truly collapses, especially in the field of injection molded internally threaded closures, which we are all familiar with in our everyday life, has been the engineer's dream for many years.

Many a mold designer has spent countless hours trying to conceive of how to arrange and rearrange, shuffle and reshuffle, split and re-split, and finally how to activate the components of a core in an injection mold in such a manner as to release for ejection a part which has had a continuous internal undercut molded into it.

A truly collapsing core, one which meets these conditions - that of retracting its own periphery toward its own center to permit ejection of an internally threaded, molded part - may, in the near future, become a practical reality.

Most of the injection molded caps and various closures having internal threads are almost invariably molded with cores actuated by rotating mechanisms which affect release by unscrewing the core from the molded part, or sometimes vice versa. As serviceable and as well designed and built as these molds are, they generally are quite complicated in design and consist of many moving parts, conditions which usually indicate possibly relatively high maintenance costs and perhaps a fair share of "down time" to permit adjustments or repairs.

CONSTRUCTION AND OPERATION

The collapsible core we are considering today circumvents many of the usual design requirements of conventional closure molds because of its principle of operation and because it does not require the number of parts usually found necessary in unscrewing molds. The collapsible core is completely self-contained and operates independently of any other similar cores which may be in the same mold. There is no mechanical connection between any of the cores in one mold, and neither is there any central or common actuating force or device necessary to its operation.

The collapsible core is an assembly made up of only three components, a center core pin, a sleeve and a safety ring. It is the sleeve which is the key member of this assembly and which does the actual collapsing, thus removing itself from the undercut portion of the molded part, permitting the part's ejection from the mold.

For the purposes of this discussion it will be assumed that an internally

threaded closure is to be molded and the collapsible core is to be utilized to mold the thread. To begin to visualize its construction and operation, let us look at a simple schematic partial assembly of how this would look in a mold as we refer to Figure 1.

Here we see the molded cap, the collapsible sleeve which molds the internal thread, the center core pin, the cavity insert, stripper plate and ejector plate assembly. The safety ring which was previously referred to has been omitted for the time being. The core pin is assembled inside the collapsible sleeve and together they form the punch or core side of the mold, along with the stripper plate which is used to eject the part.

The collapsible sleeve itself is a specially shaped sleeve whose upper half, approximately, consists of a series of matching, vertical segments extending completely around its diameter. These segments are of two types, wide and narrow, alternating around the periphery of the sleeve, as shown in Section A-A and the right side view. These segments are "free" at one end, the end which molds the internal thread and has the thread contour cut into it. The other ends of the segments merge with and become a part of the solid portion of the sleeve, as can be seen in the view at the right.

These segments are, in effect, somewhat like the tines of a fork (let us say a circular ford), "free" at one end and part of the solid structure, or the sleeve proper, at the other end. These segments, though separate at the molding end, are so close together and so perfectly matched with themating surfaces of adjoining segments, that no molding material can flash between them. Further, these segments have cut-outs at their sides, adjacent to each other, below the molding surface, which give the effect of slots and materially alter the cross section of the segments.

These segments, with their special shapes and slots, produced by unique machining, grinding and other fabricating techniques, have had, by reason of this reworking and because of the steel they're made of and subsequent tempering, imparted to them unusual flexing qualities. These segments actually act as "leaf springs" with one end "free" and the other end "fixed", and it is this flexing characteristic which causes the actual collapse. The flexing begins at the "pivot point" at the beginning of the segments at the bottom of the slots (where the movement is zero), and extends upward to the top of the free end of the segments (where the movement is a maximum).

When the core pin is inside the sleeve in molding position, the sleeve segments have already been flexed or "expanded" outwardly by the core pin to the correct molding position and are in a preloaded or stressed state. When ejection takes place and the "restraining" core is retracted, collapsing of the sleeve segments, or the moving inwardly of the separate segments, automatically takes place.

The word "restraining" is used very purposely because that is exactly the condition that exists between the core pin and the collapsible sleeve in molding position when the press is closed. As ejection later proceeds and the core pin moves away from the front or top of the sleeve, the sleeve collapses, with the segments merely reverting to their "free" or unstressed condition and position. In their normal or "at rest" state, the segments are in the "inward" or retracted position, thus releasing the molded thread.

This can be seen at the upper two views where designation is made of the root diameter of the thread. In the left view, which is the molding position and the uncollapsed state, the root diameter of the thread is seen as being held in by the

sleeve, but in the right view, which is the collapsed state of the segments, it can be seen that the root diameter of the thread is clear of the sleeve segments and, therefore, ready for final ejection.

There is another design feature just barely mentioned before that should be re-emphasized here, for without it, the sleeve, with all of its "built-in" flexing properties, still could not function, and that is the precise shape of the segments.

It is true that when the center core pin is withdrawn at ejection, the segments collapse, but what permits this action to take place is the fact that alternate segments are narrower than the others, and therefore, they flex differently so that their "free" or unstressed position is different from that of the wider segments. Consequently, the narrower segments after collapse are "at rest" along a circumference which is smaller in diameter than that of the wider segments, as can be seen in the collapsed section at the upper right.

This means that the narrow segments collapse a greater distance than the wide segments, and this, along with one other necessary provision, that of the correct angle at the sides of the segments, makes possible the collapse of the sleeve segments without the "jam-up" that would occur if all the segments tried to collapse the same distance. It can be seen, by referring to the upper right view again, that as the segments collapse, the narrow segments "make room" for the wide segments and "dovetail" with each other, permitting them all to collapse without interference.

These, then, the segments, their flexing properties and their alternate dissimilar shapes are the actuating principles and the manner of operation of the collapsible core.

SEPARATE COMPONENTS

To look briefly at each part separately, let us turn to Figure 2. Here we see the core pin, made of hardened steel, which assembles inside the collapsible sleeve. A taper has been provided at the end of the pin where it will match a similar taper on the sleeve. A drilled hole is shown in the center to provide proper cooling in the mold.

The area outside the working length is ground off before installation, or, if necessary, the shoulder can be utilized as part of the core. Centers have been indicated at the end to enable the mold maker to perform additional work that may be required. In the mold the core pin is installed in the back clamp plate and, of course, works inside the collapsible sleeve.

For the collapsible sleeve let us refer to Figure 3. The hardened steel sleeve has a taper on the inside diameter at the end where it will match the taper on the core pin. The segments at the end are shown in the uncollapsed state, even though when the core pin is removed, as it is in this figure, the segments would be in their "normal" or collapsed state. This was shown, however, in a previous view, Figure 1. These segments, shown as they would appear in molding position, must fit and match each other so that there will be no flash from the molding material.

To hold the sleeve and core pin in proper relation with each other while additional work is being done on the sleeve, three tapped holes for set screws have been indicated. It will be noticed there are little lugs sticking up on each of the segments. These have been incorporated because of their effect on the strength of the segments and because they are necessary in conjunction with the operation of the safety ring which is shown in Figure 4.

This hardened steel ring slips over the outside diameter of the collapsible sleeve and has one important function. If the segments of the sleeve do not start to collapse, because of possible material adhesion, at the proper moment during ejection, this safety ring, by reason of the chamfered bead around its inside diameter, engages the lugs on the segments and acts as a cam in forcing them to collapse. The segments are compelled to "break" and they then continue the remainder of their collapsing action. This ring is fastened to the support plate and mounting screw holes are shown.

ASSEMBLY REQUIREMENTS

To show the assembled relationship of these three parts, the core pin, the collapsible sleeve and the safety ring, let us look at Figure 5. Here have been indicated dimensions or locations which are interrelated and of necessity must be held when incorporating the collapsible core into a mold. When a collapsible core of this type is first conceived and developed, certain dimensions concerning basic relationships and movements must be arbitrarily decided upon and assigned, and it is these specifications which become important in mold design and construction. In line with this, it will be seen that a note in the illustration calls for all dimensions indicated by letters to be observed in mold design.

The first interrelated dimension to be held is indicated by the letter "A". This dimension is the distance between the end of the collapsible sleeve and the collar of the core pin. This dimension guarantees that the outside taper on the core pin and the inside taper of the collapsible sleeve at the molding end are perfectly matched, and insures the proper "spread" of the segments to their correct molding position. By "spread" is not meant that the segments are apart, but only that they have been re-positioned from their collapsed, or unflexed state to their fully flexed or stressed condition and location, which in reality "pre-loads" the sleeve for its collapsing action when the press opens and ejection takes place.

Dimensions "B" and "C" indicate the length of the core pin and the sleeve, and dimension "G" shows the tip of the core pin which would ordinarily be ground off after the threads are ground on, unless this area is necessary for the part configuration. At any rate, the extreme tip above "G" is always removed prior to installation in the mold. Dimension "D" is the length of thread or extent of undercuts that can be molded, including the shut-off area in the mold.

Dimension "F" is the distance between the end of the collapsible sleeve and the safety ring. This is important because the safety ring must be properly positioned in order for it to come into play at the proper time to perform the job for which it was designed, that of forcing the segments to break at ejection if, because of material adhesion, they fail to do so. The "spring" action of the segments would then take over and complete the collapse. The distance between the lugs on the sleeve and the bead on the inside diameter of the ring is just right to perform this safety function.

Dimension "E" indicates the amount of ejection travel required (or core pin retraction), to fully collapse the segments of the sleeve, thus releasing the part for final ejection from the mold. This dimension can be considered as a "range" rather than an absolute dimension, having a minimum distance requirement to achieve collapse, and a somewhat greater value that may be used if it is better adaptable to other mold conditions.

It can be seen, then, that assembly dimensions are not only important, but necessary in the proper design and construction of the mold, to insure proper

operation of the collapsible core, from molding on through ejection.

GRINDING REQUIREMENTS

There are some precautions to mention in conjunction with the grinding of the thread on a sleeve of this type which it would be well to observe, and for this let us look at Figure 6. Here we will note that the core pin and sleeve have been locked together in the proper position by screws so that there will be no movement between them which would tend to produce incorrect configurations. Care should be taken to see that the diameters of the sleeve and core pin are also concentric.

The finished ground thread has been shown, including the tapered shut-off below the thread. This taper is important because the stripper plate seals off at this area and at the same time properly positions the segments in correct molding position as the mold closes.

A clamping ring fixture is also shown which locks the segments together and holds them tightly against the core pin, keeping them from shifting during thread grinding. Care should be taken to see that the ring fixture is clamped on only within the area that the collapsible sleeve and core pin have a matched tapered bearing surface in common. To clamp and bear outside of these confines, as can be seen in the schematic view, would put pressure on unsupported segments and tend to spread them apart, adversely affecting the thread grinding operations and permitting grinding dust to enter.

During grinding it would be advisable to take light rather than heavy cuts, especially as the finished contour is approached, and to use light pressure, rather than heavy, for lubrication and air cleaning because of the danger of grinding dust being forced between the segments. It might be well just before finish grinding to completely disassemble the units, clean and reassemble, and then proceed with the final operations. Now, for other considerations.

ANALYSIS OF RADIAL COLLAPSE

The question probably arises, "How far does the core collapse?" and from this, a corollary question would follow, "How deep an undercut can be molded?". Before these questions can be answered, it would be well to analyze a little further the nature of the collapse.

It was mentioned a little earlier that the segments are somewhat like the times of a fork (except very close together), being free at one end and becoming a part of the solid structure at the other end. It would then follow that the collapse inward at the free end, since its action is somewhat like that of a stressed leaf spring fixed at one end, would be maximum at the free end and zero at the end where the segment becomes a part of the body proper. In between, then, the amount of collapse would lie between these two extremes. Now since the molding portion of our sleeve is all near the free end, it would be this area, and roughly the inside height of our molded part, generally speaking, which we would be concerned with. Actually, it would be the amount of collapse occurring at a point coincident with the lowest part of our internal thread or undercut, that is, that point on the undercut which is furthest removed from the top of the molded part. If the part, or cap, had a molded internal thread for the full height of the inside of the part, the point in question would be at the bottom of the part, or generally speaking, at the parting line. What the amount of collapse would be at this point would be of vital importance. To look at this radial collapse pictorially let us turn to Figure 7.

We notice here an enlarged schematic view of the collapsible core showing the wide and narrow segments and their uncollapsed and collapsed positions. Also shown, for discussion purposes, is a molded cap which has internal threads for an inside height of 1 inch. At the right is shown a graph indicating formulated radial movements at full collapse of a core which will be referred to as "Type 3".

Let us assume that the collapsible core shown is in a mold, and that the core pin has just been fully retracted by normal press ejection and that the sleeve segments have fully collapsed inwardly, away from the molded internal thread, as seen in the lower left hand view. Now, by the nature of the collapsing action, the collapse is greatest at the top of the segments and the least or zero at the bottom of the segments at the pivot point of the flexing action at the end of the slots where the segments actually begin and where the flexing movement likewise begins. Because of this, then, the amount of collapse at the top of the thread would be greater than the collapse at the bottom of the 1.000 inch dimension. But not only this, the amount of "effective" collapse at the edge of the wide segment is less than the amount of collapse at the center of the wide segment.

Let us look up at the plan view at the top and notice Point "A" which is at the center of the wide segment. Its direction of radial movement or collapse is perpendicular to the diameter or wall of the molded part and, therefore, its full movement is also its "effective" movement.

However, if we look at Point "B", which is at the edge of the wide segment, it will be noticed that its direction of movement is parallel to the direction of movement of Point "A" and, therefore, not perpendicular to the diameter or wall of the molded part. Its movement is obliquely across the molded wall thickness and, therefore, its "effective" collapse in terms of releasing its own undercut is less than the collapse at Point "A", or the center of the segment.

It is evident, then, the collapsible core has certain "collapse characteristics" which must be examined before any particular part can be considered for molding with the collapsible core. To provide for this necessary information, values have been worked out for full collapse for a core referred to as "Type 3" and are indicated on the graph of radial movements shown at the right.

Vertically are shown values of radial movement per side in inches, and horizontally have been indicated distances from the top of the core in inches. Two sets of resultant values have been plotted, one set of radial movements at the center of the wide segment or Point "A", and one set of radial movements at the edge of the wide segment or Point "B".

To illustrate, let us notice the differing radial movements at various heights along our molded cap, referring also the the view at the left. At the very top of the core the radial movement is .080" at Point "A", and .068" at Point "B". At a height (or distance from the top of the core) of .500", the radial movement at Point "A" is .068" and at Point "B" .058". At a height of .750" the radial movement at Point "A" is only .0625" and at Point "B" only .053". These points can be checked easily on the graph, as well as any other desired point, up to the full 1.000" height of the molded thread.

It will be noticed that nothing has been said about the amount of collapse of the narrow segments. It will be remembered that earlier it was pointed out that the narrow segments collapse farther than the wide segments and, therefore, they do not become a factor in determining minimum collapse.

Once the mold designer has the required radial movement information, he can decide how deep a thread and how long a part can be molded with the collapsible

core. The depth of thread is important for another reason also, and that is the amount of steel remaining on the segment behind the thread. Care must be taken so as not to reduce this distance below the safe minimum required to maintain adequate strength in the segment and not to alter its flexing characteristics, as indicated in the view at the left.

RANGE OF SIZES

Something is probably expected to be said about the sizes of threads that have been considered for the collapsible core. This matter has been given some attention and a chart is shown in Figure 8 giving tentative and approximate values which have been formulated for a range of sizes for the collapsible core which will be called Type 2, 3 & 4. It becomes evident that not all sizes of threads could be molded with one size of collapsible core, therefore, the several sizes.

The values that would interest the molder and consumer most would be the maximum and minimum O.D. of the thread, the molded length (including shut-off in mold) and the collapse per side. These are denoted on the chart by "A", "B", "C" and "G", respectively. The other values shown, I.D. of collapsible core, "D", and maximum and minimum thickness of steel wall into which thread would be ground, "E" & "F", are important primarily to the mold designer for it is he who must insure that the limits of safety have not been exceeded which would jeopardize the structural soundness of the segments.

It will be seen that the range of O.D. of threads is 1.100" to 1.390" and 1.390" to 1.740" and 1.740" to 2.182". The molded length for these is .975", 1.225" and 1.535", respectively. The amount of collapse for each is .080", .080" and .095", again respectively. These figures cover threads having an O.D. of from 1-1/8" approximately to 2-1/8" approximately. It should be remembered again, as indicated on the chart, that these values are purely tentative and approximate and are used only as a basis for this discussion.

MOLD DESIGN

Before concluding, some illustrations of mold design should be shown, and accordingly, let us look at Figure 9, which shows a schematic mold assembly of a molded cap with edge or tunnel gating. Here we can see the relationship of the collapsible core with its own components and also with the rest of the mold.

It can also be noticed that the items mentioned in Figure 5 as being required to be observed in mold design are really important, for they position the collapsible sleeve in the ejector plate, the core pin in the back clamp plate and the ring in the support plate, the latter at the required location to fulfill its safety function. A stripper plate has been incorporated for proper ejection and cylinders are shown installed for the last stage of the required two-stage ejection. Guide pins are shown in the ejector plate to help maintain alignment, which is vital in a mold of this type. A baffled cooling line is provided in the core, and customary cooling lines are indicated in the cavity and core plates. The .005" dimension at the top of the core allows the sleeve segments to slide under the wall thickness of the molded part without any interference.

The molding sequence can easily be followed by starting with the press opening. When the press opens and the mold parts at the parting line, the material at the tunnel gate should break, leaving the part free from the runners. As the press continues to open, ejection begins to take place by way of the press knock-

out bars, indicated by the K.O. hole shown.

This is the first stage of ejection and during this time the ejector plate with the collapsing core is moving forward the necessary stroke to retract the core pin the required distance to attain full collapse of the sleeve. If the segments fail to begin collapsing, during this stage, the safety ring will come into play as its inner bead contacts the lugs on the sleeve, causing an initial break followed by normal collapse. The stripper plate is also moving with the ejector travel, being actuated by the return pins, located directly under it.

The stripper plate and ejector plate move together until the "stop" is reached at the end of the first stage of ejection, at which time the cylinders "take over" and continue to move the stripper plate through the second stage of ejection, stripping the part from the collapsed sleeve.

For another type of mold design, let us refer to Figure 10, which shows a schematic mold assembly of a molded cap, center gated, with 3 plate mold construction. An accelerated knock-out system has been incorporated for the final phase of the stripping action, in place of the cylinder shown just previously. An extra runner plate has been added to allow for top center gating. The mold components are otherwise pretty much the same as in the previous mold.

There will, however, be a difference in mold sequence due to the 3 plate construction. As soon as the press opens, the mold opens first at the top runner plate, the runners becoming free because of the puller pins and runner back-hooks. The next opening will be at the normal parting line, and as the mold continues to open, ejection will commence by way of the press knock-out bars. Simultaneously, of course, the sleeve will collapse as the core pin retracts and the stripper plate also comes into action.

The ejector travel will be conventional until the accelerated knock-out unit contacts the actuating pin, causing a "swivel action at the accelerated K.O. unit. This action, through the return pins, makes the stripper plate move faster than the ejector plate, with the result that the part will be stripped from the collapsed core. As can be seen by the note at the left side of the assembly, the total travel of the stripper plate will be greater than the travel of the ejector plate, thus accounting for the removal of the part from the sleeve.

The final mold design, Figure 11, shows a schematic hot runner mold assembly with a center gated part. This has a double ejector system for the 2-stage ejector travel required. This necessitates a longer core pin to extend through both ejector plates, but the collapsible sleeve remains the same.

As the press opens and the mold parts at the parting line, there will be no sprue or runners to remove because of the hot runner design. As the press continues to open, at the proper time the two ejector plates, locked in tandem, will begin to move, actuated by the press knock-out bars, causing the sleeve to collapse as the core pin retracts, the stripper plate also moving at the same time. The locking together is shown as being accomplished by a latch mechanism which keeps the two ejector plates moving until the latch pin is out of the upper ejector plate at the end of the first stage of ejector travel. The latch plate then retracts and permits the lower ejector plate to continue through the second stage of ejector travel, thus completing the stripper plate action in removing the part from the collapsed sleeve.

The mold sketches have been shown as a basis for discussion, and undoubtedly other designs, where variations permit, reflecting preferences and practices of

molders and mold designers, will suggest themselves as occasions may arise.

FUTURE OUTLOOK

For those who might be wondering if the collapsible core is actually operational or perhaps only a laboratory specimen, with some promise, let us refer to Figure 12. Here are shown 33 mm closures with internal threads, molded with the collapsible core. The core has performed up to preliminary expectations and its functioning has given rise to optimism about its possibilities. And what are its possibilities?

First of all, the mold can be much simpler than conventional closure molds now in use. This mold needs no racks, pinions, gears, hydraulic motors or any complicated powertrains or actuating mechanisms for its operation - just three simply operating parts - and the mold movements required are all conventional.

Secondly, the parts themselves can be extremely varied in nature. The internal threads need not be continuous, they can be interrupted, or, in fact, they need not be threads at all. The undercuts can be beads, dimples, bumps, depressions, cut-outs, or almost any shape, uniform or non-uniform, and singly, in groups or in tiers, as long as they are within the radial movement limits of the collapsible core.

Almost all of these are shapes which have been virtually impossible to injection mold, and this, to some degree, has set limitations on product design. Although the collapsible core has been developed with round parts in mind, it appears that there might be reason to believe that other shapes for special applications might bear looking into.

Then, lastly, what effect has the collapsible core had on molding cycles, an an area where product cost is involved? The very fact that complex unscrewing mechanisms, whose operations generally require a sizable portion of the molding cycle, have been eliminated, would tend to point to an appreciable reduction in cycle time, and, therefore, consumer cost. This is exactly what has happened where the collapsible core has been instituted and a check made on corresponding cycle times.

All in all, the collapsible core appears to be possibly nearing the threshold of materially affecting the method of production of caps and closures, and to be opening up entirely new areas of product design and application, which will serve as a challenge, collectively, to all of us, to our creativity and resourcefulness, and will extent the scope and usefulness of our service to the plastics industry.

ACKNOWLEDGMENTS

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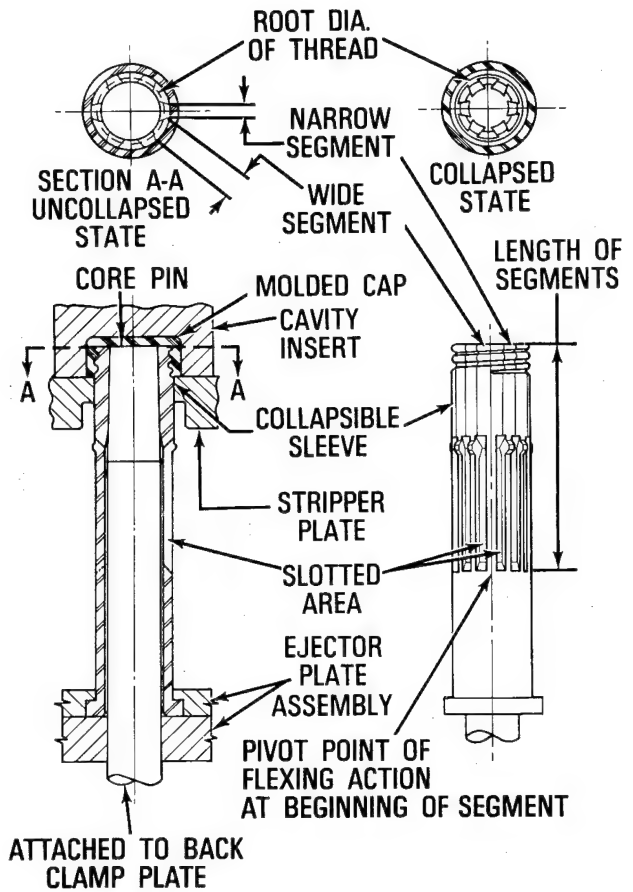
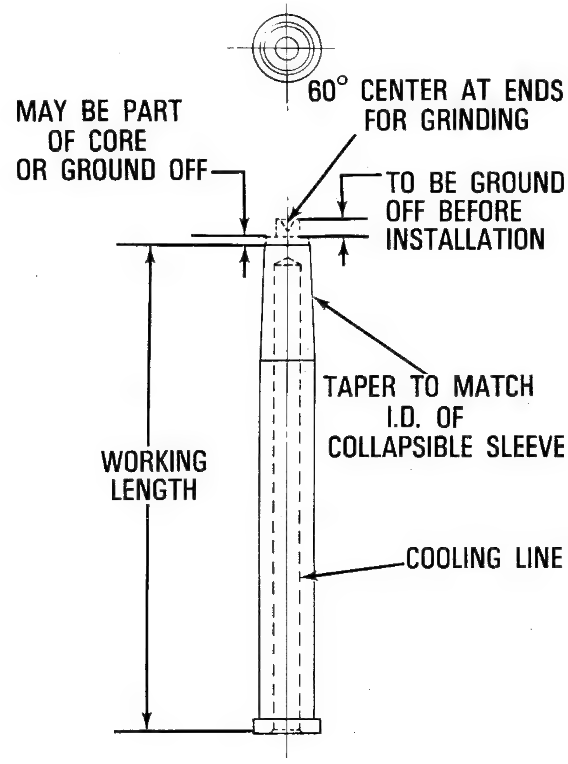
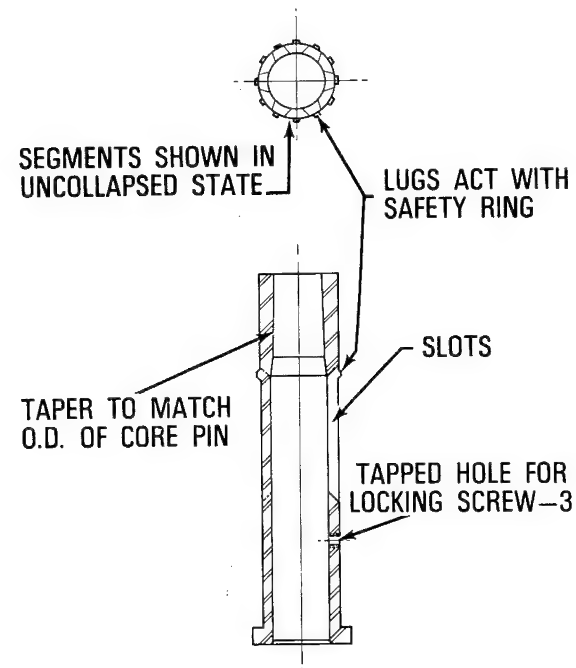


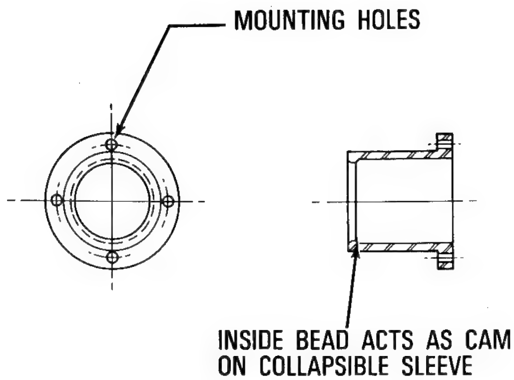
SCHEMATIC PARTIAL ASSEMBLY OF COLLAPSIBLE CORE
FIGURE 1



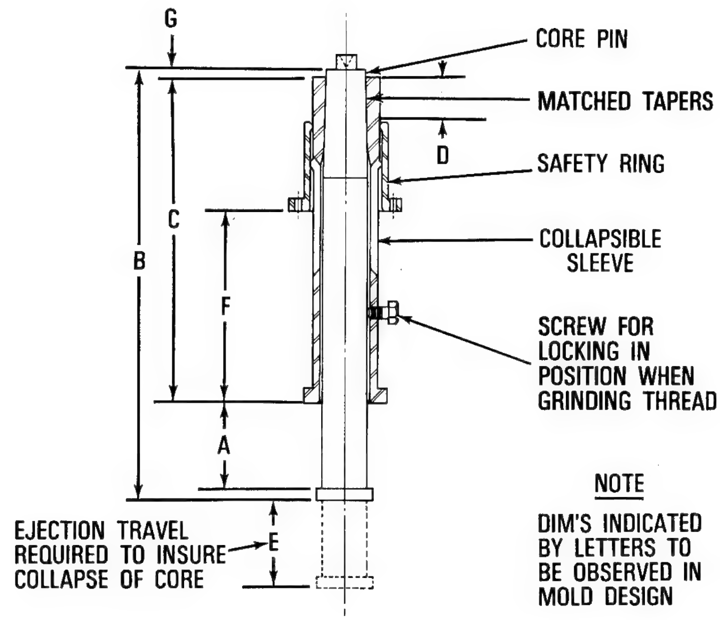
SCHEMATIC VIEW OF CORE PIN
FIGURE 2



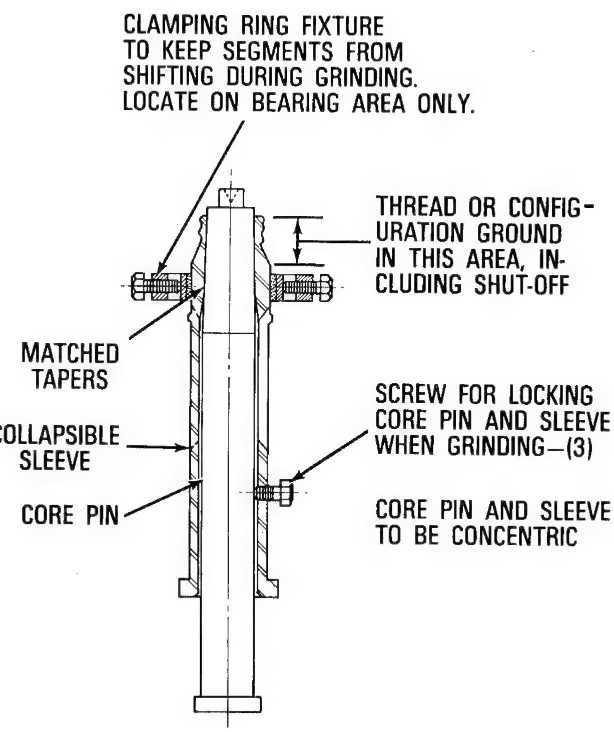
SCHEMATIC VIEW OF COLLAPSIBLE SLEEVE
FIGURE 3



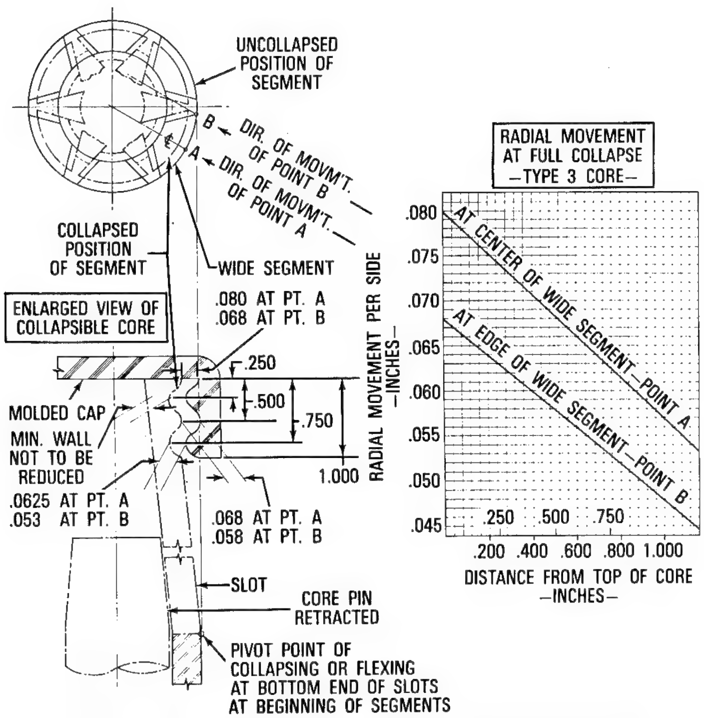
SCHEMATIC VIEW OF SAFETY RING
FIGURE 4



SCHEMATIC VIEW OF COLLAPSIBLE CORE ASSEMBLY
FIGURE 5



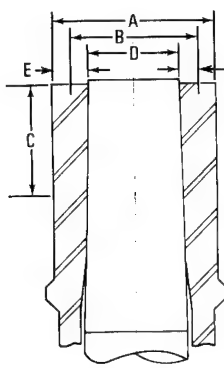
SCHEMATIC VIEW OF COLLAPSIBLE CORE GRINDING ASSEMBLY
FIGURE 6



SCHEMATIC VIEW OF ANALYSIS OF RADIAL MOVEMENT OF COLLAPSIBLE CORE
FIGURE 7

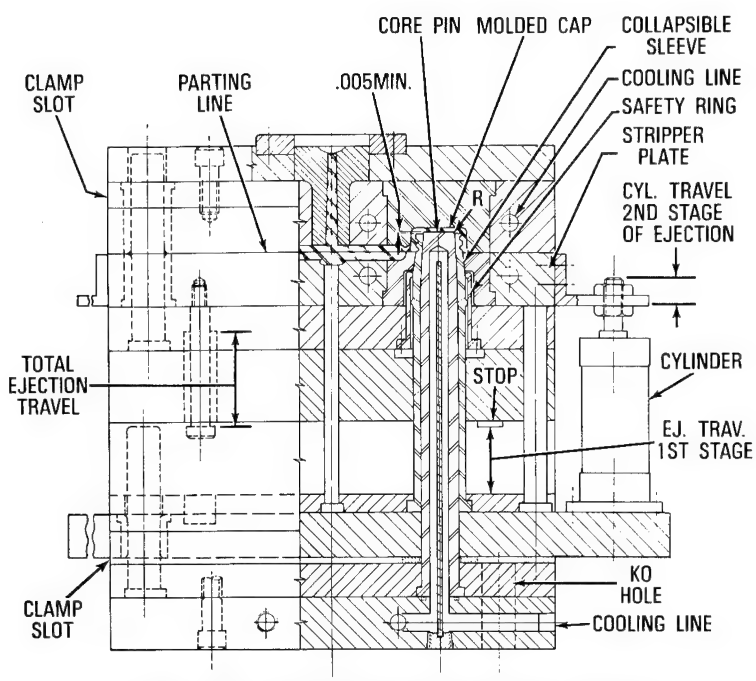
TYPE CORE	2	3	4
A—MAX. O.D. OF TH'D.	1.390	1.740	2.182
B—MIN. O.D. OF TH'D.	1.100	1.390	1.740
C—MOLDED LENGTH	.975	1.225	1.535
D—I.D. OF COLLAPSIBLE SLEEVE	.885	1.105	1.385
E—MAX. STEEL WALL THICKNESS	.2525	.3175	.3985
F—MIN. STEEL WALL THICKNESS	.1075	.1425	.1775
G—COLLAPSE PER SIDE (NOT INDICATED)	.080	.080	.095

NOTE—VALUES SHOWN ARE TENTATIVE AND APPROXIMATE ONLY

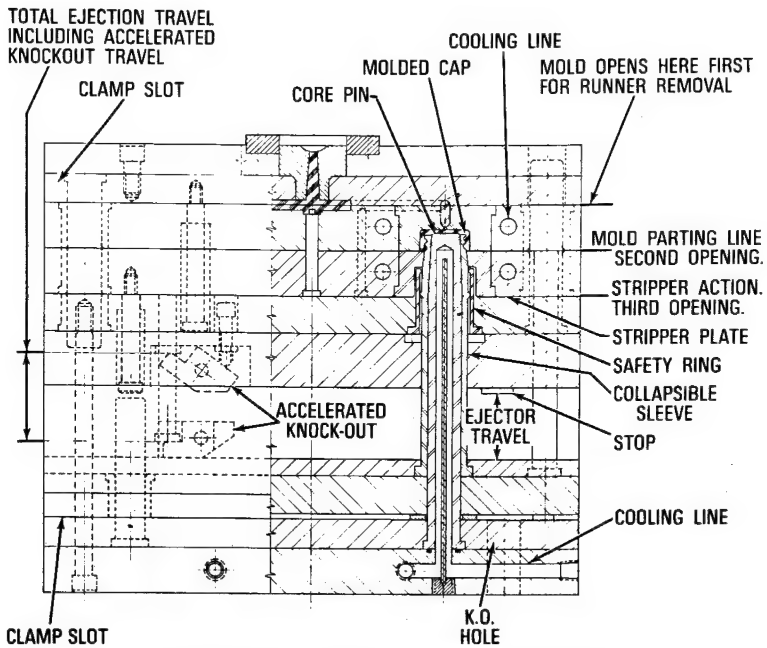


SCHEMATIC VIEW OF CORE PIN AND SLEEVE

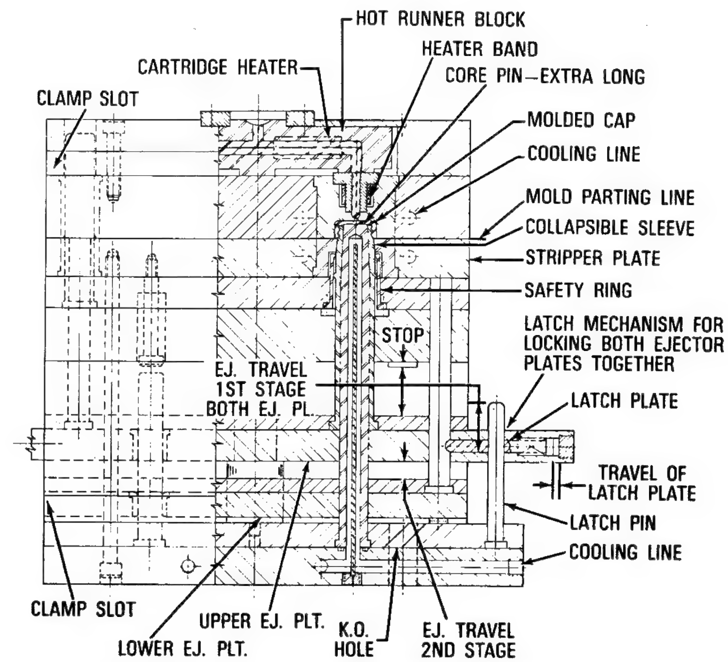
A RANGE OF SIZES FOR THE COLLAPSIBLE CORE
FIGURE 8



SCHEMATIC MOLD ASSEMBLY WITH EDGE OR TUNNEL GATED PART
FIGURE 9—COLLAPSIBLE CORE



SCHEMATIC MOLD ASSEMBLY WITH CENTER GATED PART
FIGURE 10—COLLAPSIBLE CORE



SCHEMATIC HOT RUNNER MOLD ASSEMBLY WITH CENTER GATED PART
FIGURE 11—COLLAPSIBLE CORE

FIG. 12—SAMPLES OF CLOSURES
MOLDED WITH THE COLLAPSIBLE CORE

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TOOLS FOR INJECTION BLOW MOLDING

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INTRODUCTION

Injection blow molding, as the name plainly implies, calls for tools to carry out an injection molding operation and then to post-form the injection molded part by blowing, whereby the transfer of that part from the first to the second step is performed automatically, linking the two steps into a single, sequential process.

The design of injection molds, the same as that of blow molds, may certainly be presupposed to have been amply covered, by experience and literature, as have many automatic transfer devices for the removal and repositioning of injection molded parts from the mold directly. Whatever distinguishes an injection blow molding tool from a mere assemblage of an injection mold, a blow mold and a transfer device, can only be illustrated out of an understanding of the injection blow molding process as a whole.

With that understanding, the demands which a tool-set must satisfy may be spelled out in terms of general tool-components' specifications. The experienced mold designer should find these specifications sufficient to translate into drawings that show the dimensional relationships correctly and, at length, into a tool which will turn out acceptable products when used in a machine which was designed with no less consideration of the process than has gone into the tool.

It is ~~will~~ be attempted here to convey an understanding of the process of injection blow molding and to relate it step by step, to the individual components and to the functioning of these components in an assembly.

THE PROCESS AND THE COMPONENTS OF A TOOL-SET

The injection blow molding process entails injection molding a parison, transferring it into a blow mold and expanding it therein by internal fluid pressure. Figure 1 provides a schematic illustration of these basic steps.

Accordingly, a typical injection blow molding tool-set has the following elements:

1. The parison mold, which is an injection mold, usually consisting of a base, a pair of body-mold halves and a neck ring.

2. The blow mold, in most cases having a pair of halves and occasionally also cores or slides, not unlike blow-molds in the extrusion-blow process.

3. The blow core, which functions first in the parison mold as the core around which the parison is injected; then, usually together with the neckring, as the transfer tool to convey the parison from the injection mold to the blow mold; next, as the valve through which blow-air is admitted to expand the parison in the blow mold; and, at times, as a force plug to assist parison expansion mechanically.

While these elements are present in all injection blow mold sets, they differ, depending on the size and shape of the end product. The end product is usually one of the following:

1. A bottle, having a narrow neck with finish and a comparatively long, usually contoured body.

2. A jar, or wide mouth container, having a wide neck, usually with finish, and a relatively squat body, larger but not by much, than the neck.

3. A cup, or open top container, having a finished rim and a body which is smaller than the rim.

4. A tube, having a narrow neck with finish at one end, a finished rim at the other end and a body between the two which is usually cylindrical, except near the narrow neck end.

From the standpoints of process detail and tool design, the ratio of neck (or rim) diameter to the length of the container is the single most important characteristic of the product to be made. Depending on that ratio, the tool elements will vary, generally in the following ways:

	Bottle	Jar	Cup	Tube
Parison mold				
base	separate, single piece	integral with body	integral with body	separate, single piece
body	split	single piece	split	split or single piece
neck-ring	split	split	single piece	single piece
Blow core	centered end	free or centered end	free or centered end	centered end
Blow mold	split	split	single piece	split or single piece

Parisons are designed to satisfy two purposes:

1. To expand into the intended shapes and, in so doing, to change their wall thickness distribution into those of the blown articles.

2. To contain, in finished form, all parts of the end products which are not to be postformed by blowing.

Since practically all such parisons are to be made into containers and because it is obviously preferable to injection mold, rather than to blow mold the neck (or rim) of a container, the neck is finished in the injection step (the bottle molder calls the neck "finish" for that reason). The body of the container in turn is blown and hence, that part of the parison which is to provide stock from which to obtain the ultimate wall thickness distribution of the end product must be dimensioned accordingly.

This critical interrelation of parison and finished-product wall thickness distributions is not governed by geometric and dimensional relationships alone: It is not possible to dimension a parison "backwards" from the finished wall thickness distribution, as say merely by multiplying that thickness by a factor corresponding to the blow-up ratio, except perhaps as a first, rough approximation. Instead, the temperature distribution in the parison at the time of blowing and the visco-elastic behavior of the plastics corresponding to that temperature distribution must likewise be taken into account, and also, the response of the plastics to its processing history preceding completion of the parison molding operation.

If the plastics contained in the parison were all at the same temperature at the time of blowing, and the parison itself were of uniform wall thickness, a simple geometric relationship could be forecast and accordingly, a parison (therefore, also a parison mold) designed arithmetically from the finished product. However, parisons never have the same thickness throughout, nor is the plastics ever at uniform temperature. It exhibits temperature gradients along the length and circumference, and within the wall of the parison.

Also, after-effects of injection exist, notably elastic recovery in keeping with the degree of packing of the parison cavity which in turn depends on the efficacy of the injection control used.

As in a defective toy balloon, a parison will not expand as it should if it contains a region whose resistance to deformation by blowing is markedly lower than that of the rest. The same as the balloon will thin out at an originally thin spot and expand locally into a bubble after very little, if any, expansion of the rest, so will a parison, at its worst, produce a film bubble and burst in "weak" regions. A thick area which is hotter than an adjoining thin region may well move first, and move so much that it may be too late for the rest to follow. (Temperature equalization by conduction is, of course, not to be counted on in plastics.)

For example, in the simple illustration of Figure 1, the parison is injected at its closed end and, therefore, if nothing is done to change it before blowing, that end, particularly the sprue itself, will be a good deal hotter than the region adjoining the neck; in fact, unless care is taken, failure of parison bottoms in blowing will occur in spite of comparatively great thickness.

While considerations such as these are simple enough and, if borne in mind, confer a good intuitive approach to the design and dimensioning of tools, the accurate interrelation of temperature gradients, mechanical behavior of the plastics and dimensions is so complex that parison design, in the end, is always the result of "cutting and trying", with the designers intuition and experience as a starting point. Consolation may be had by appreciating that the glass container industry, after many decades of industrial experience - and before that, centuries of artisanship - to this day designs its tools from an educated guess.

The tool-set must be designed not only with dimensional relationships in mind, but with full recognition of the need to provide consistent control of the process variables which influence dimensions as much as dimensional variations influence the processing characteristics.

Not all of the processing variables can be affected, let alone be controlled by the tools, but the ones that can be so controlled, must be. Thus, molding pressure, melt temperature, accuracy of cavity fill and packing, rate of blowing, are not for the tool to control. On the other hand, one of the most significant processing variables, the temperature distribution at the time of blowing, is definitely for the tool to determine; in fact, there is nothing else to control it reliably.

Needless to say, the parison dimensions and the external dimensions of the blown article are given by the tools alone. The wall thickness distribution of the finished product is also governed by the tool, but not solely though dimensional relationships: The temperature of the parison, as controlled by the tool, has equal influence.

Bearing in mind this general outline of the problem that injection blow molding presents, one may detect just where these tools differ from other known injection molds and blow molds alone, or in combination.

Two things sum up the problem which must be accounted for everytime - tool alignment and temperature control.

It is taken for granted that the tools are built accurately; that is, the components are machined and finished properly and assembled correctly, as they should be in any injection mold. Tool alignment means more; it concerns impeccable fit and positioning of tool and transfer components which move in relation of one to the other, rapidly and frequently.

Temperature control, too, means a lot beyond the normal function of mold cooling; it is not sufficient, as one does in most of injection molding, merely to cool the article enough to be ejected without harm. Instead, one must maintain carefully predetermined gradients of temperature, the extremes of which range from near room temperature to near the melt temperature, all in the same piece, at the same time, from one cycle to the next, which may follow each other very few seconds apart.

The novelty of injection blow molding tools resides in an unusual concentration of critical features, hardly any of which are new, except in the combination called for here.

For example, the accuracy and reliability of temperature control of a parison mold is not unlike that of an injection mold for strain-free, or optical parts. The alignment of a blow core resenbles that of a barrel core in fountain-pen and flash-light cases.

It will, therefore, not be difficult for the experienced tool designer to succeed here if he will do nothing more than avoid short-cuts and "simplification" when it comes to the parts of the molds that are necessarily based on critical features of the process.

PARISON MOLD ALIGNMENT

The parison mold consists of three major elements:

1. The body, to shape the outside of that position of the parison which is later to be postformed, i.e., blown.

2. The neckring or rim forming tool, to shape the outside of the open end of the finished product.

3. The blow core, to shape the inside of the parison, in the body and in the neckring. (Functions of the blow core outside the confines of the parison mold will be considered later.)

These three elements must be in perfect alignment throughout the injection step. Moreover, they must co-act to reproduce a predetermined temperature profile in the parison in every cycle.

The alignment is the more difficult to obtain, the thinner and the longer the blow core.

With a short blow core of comparatively large diameter, as in jars and cups, the parison usually assumes a contour that permits removal from a single piece, rather than a split, parison-mold body. Obviously, in such a body, mismatch and misalignment in any axial plane of the parison are impossible. The neckring (in the case of jars), or the rim forming tool (for cups) is aligned with the body by way of a taper according to normal design practice.

The blow core may be supported and guided in a bore of the neckring placed above the neck forming cavity. Thus, the alignment of the tool assembly is obtained by virtue of the concentricity of the body cavity with the neckring taper and the concentricity of that taper with the guide bore through which the blow core extends into the body and, of course, the concentricity of the blow core with that bore.

Such an assembly is not unlike the one customary in cup molds and like injection molding tools. The difference is solely a matter of accuracy. Thus, in many cup or tub injection molds, depending on the intended wall thickness, core eccentricity near 0.005" may well be tolerated. With increasing eccentricity, the article will certainly not improve, but even so, it can be made and the slightly faulty tool need not be discarded. In molding a parison, excessive eccentricity does not merely lessen the merit of the product somewhat; instead, it precludes successful blowing of the parison. In other words, it results in making no product at all.

Figure 2 shows a schematic cup tool assembly. Assuming a parison wall thickness averaging 0.015" which is to be blown into a cup with a blow-up ratio of say 2:1, core misalignment by 0.005" would result in excessive thinning, if not bursting of the parison's thin side during blowing. It is, of course, not difficult to make the assembly fit with the required accuracy. It is harder to maintain the core in alignment while the parison cavity is being filled. Even small, otherwise insignificant eccentricity will cause the plastics to flow preferentially into the wider gap, i.e., the thicker part of the wall, deflecting the core still further towards the thinner part.

Bearing in mind that the core is weakened by the presence of internal channeling and, above all, because it consists of at least two parts which, between them, form the blow slot, it will be appreciated that only really squat blow cores will function reliably without any more support than above indicated to warrant their alignment with the body. The diameter must almost equal the length; a ratio of 1:2 1/2 begins to affect the reliability of the operation noticeably.

Whenever that ratio is approached, or exceeded, it is essential to support the blow core not only in the neckring bore, as above, but also at the other end, by seating it against the sprue bushing, in a manner known from molding other long,

thin closed-end tubes. As in a pen-casing, the end of a parison must not have a hole in it, of course. Therefore, the hole resulting from resting the core-end against the body-mold bottom must be closed before the parison is actually complete. The simplest, most efficient way to accomplish this is to release the clamping force holding the core against the sprue-bushing immediately after the parison cavity is filled and to allow the plastics itself to push the core away from the sprue, against a preset stop whose position, of course, determines the bottom wall thickness of the parison. A well designed injection blow molding machine will have provisions for such a releasable core lock. If not, a short-stroke (under 1/2") hydraulic cylinder may be accommodated in the mounting plate of the blow cores, a separate one being needed for each core because of the inevitable lag in filling of individual cavities in a multi-impression mold.

Actually, to provide such core support is so simple that it is advisable to do it even with squat cores, just to stay on the safe side.

It will be recalled that the blow core functions as a blow-air valve during the blowing step. To that end, a blow gap must be opened between two concentric parts of the blow core, one a sleeve and the other a stem, forming a poppet-like configuration between them. The blow slot is usually located just below the neck; it must be held forcibly and very reliably shut during parison injection, lest it become clogged with plastics which, in the case of polyethylene at least, will enter a gap of less than 0.001". The above described procedure of locking the core against the sprue bushing may provide a very convenient way to keep the blow-slot closed during injection, eliminating a separate blow-slot actuating mechanism.

Centering the free end of the blow core extends the range of neck diameter-to-length ratios markedly, bringing most of the commercially important container sizes within the feasible limits for injection blow molding, at least from the standpoint of core stability; this includes, of course, narrow-neck containers, such as the accustomed range of detergent bottles.

In designing a parison mold with centered (= supported) blow core, one must remember that the force exerted by the entering plastics against the core tip is not the only one capable of deflecting the core. The locking force, i.e., the force applied to hold the core against the sprue-bushing, may deflect, or even buckle the core, if slender enough. The core becomes a "slender column" with an axial force acting upon it, the concentricity of which depends on the accuracy and rigidity of seating at the "free" end. The greater the force, the more eccentric the seat in relation to the core axis and the more able the end of the core to turn in the bottom seat, the more core deflection will result. And, very little of it is enough to ruin the parison. Fortunately, the core hold-down force is not large: It has to withstand only the pressure of the plastics against an area corresponding to the gate which is but a fraction of the core cross section in the case of the cylindrical cores typical of bottle parisons. One must merely take care not to apply more force than needed; what may seem "safe" as a locking force may well deflect the core.

As a further precaution, it is advisable to check whether this locking force is indeed concentrically applied. It is, for example, a wise precaution to use a seal and packing free, very accurately concentric, hold-down cylinder and to make sure that the core center line coincides with that of the piston.

The seat against the sprue bushing should be anything but a ball-and-cup, which would provide freedom for the core to rotate around its end and, correspondingly to deflect much more than if it were rigidly held. With the core entering

*Patents pending

the mold body axially in the course of closing before injection, there are obvious limits to the kind of seat the core end will safely engage. A reasonably flat conical end is usually an acceptable compromise.

In principle, core support may be provided from any three or four points symmetrically arranged around the circumference of the core. The same as in the case of an end support, these support points leave voids which must be filled before opening the parison mold. Clearly, the actuation of such side-supports, much like cores in injection molds, adds complications not otherwise present; also, filling - and faultless welding - of the remaining voids is best done with the hottest plastics, at the sprue.

Unfortunately, supporting the core where it would best prevent deflection, i.e., at mid-length, is the hardest, because it is there quite difficult to close up the holes, the plastics not being particularly well deformable and the available pressure to deform it at that location being very low.

Figure 3 shows a typical narrow neck parison mold assembly in which the blow core is supported, intended for a machine which has provisions to lock and release the blow core.

The parison mold body is unparted if the parison to be made in it is short enough and sufficiently tapered to release axially when the blow core (and the neck or rim-forming tool) starts to move it. Just what the limits of length and taper are beyond which sticking occurs, even just occasionally, is not well enough determined to be offered as a guide. Certainly, they are nowhere near the corresponding amounts in a conventional, cooled mold in which the molded part shrinks appreciably away from the cavity wall. The prudent thing to do, when in doubt, is to part the mold body. Up to a ratio near 1:1.5 of diameter to length, a single piece body will be safe, unless it must have almost straight walls, which would be quite unusual, considering the accustomed container shapes. The longer the parison the more one must rely on a temperature differential between the core-side and body-side walls of the parison to help release it from the body cavity, with the aim of shrinking away from the cavity without cooling too much for the blowing step. While this is quite feasible, it takes valuable time in the midst of the operating cycle, potentially as much as a quarter of the total time. On the other hand, the single piece body mold is, of course, not as costly as a parted mold nor will every machine accept a parted mold. One must balance one against the other. In the case of mass product containers, there is seldom any question about deciding in favor of the parted mold for the sake of its greater reliability in operation and shorter molding cycle, except in obviously feasible cases like drinking cups, cream jars and similar very stocky-shaped items. The alignment of the neck-ring and blow core in a single piece body is as good as the concentricity of two diameters bored in the same setup.

As a rule of thumb, parisons which can be made in single piece mold bodies do not require end support, which will be of interest only to users of machines lacking facilities for seating the blow cores.

The parted parison mold body is usually made to suit one of the two conventional locking methods: The one used for the tool in Figure 3, a direct hydraulic toggle clamp acting perpendicularly to the parting plane, or the one indicated in Figure 4, in which the body consists of two halves held in a retaining ring on a tapered side wedge and in which the locking force acts axially against the ends of these halves. No details need be shown for these configurations, because both are completely conventional.

The only noteworthy consideration from the standpoint of dimensions and alignment concerns the sprue and mold bottom. They should be separated from the two body halves; in other words, the sprue must not be split.

It is very difficult, if not impossible, to place the parting plane of the body mold exactly into the same position relative to the axis of the blow core every time the mold halves close, except with inordinately expensive and "fussy" clamping means. Therefore, the parting plane of the closed mold is best not used as a reference in the alignment of the blow core with the rest of the parison mold cavity. With the blow core seating against the sprue after closing of the mold, one would do just that if the sprue were parted and each half attached to a corresponding body-mold half.

To avoid this, the parison bottom forming member is made of a single piece and movable only axially, over the small distance necessary to break away from the injection nozzle. Accordingly, the assembly is aligned as follows: The blow core tip engages the sprue bushing; the body mold halves then close in a plane whose position relative to the blow core axis is given by an abutment provided on the outside of the fixed bottom forming part of the mold and, at the other end, by the outside locating surface of the neckring.

Thus, the alignment is provided "from the inside out", using the blow core axis as a center-line and concentrically therewith - moving radially outward, the sprue bushing and bottom cavity, the neck ring and neck ring bearing and the body mold. If the blow core is straight, the locating surface of the bottom piece concentric with the sprue, the locating surface of the neck ring concentric with the neck ring axis (and the latter con gruent with the blow core axis), and the body mold cavity concentric with the top and bottom locating surfaces of the mold, then the assembly will be properly aligned without having to use actuators for the several moving components. In other words, a machine which is built to jig-borer tolerances.

The one characteristic of an injection blow molding machine that contributes no end to the successful operation of a parison mold concerns the movements of the blow core and neckring as imposed by the machine. If the movement of these tool components is axial only,* rather than actuated by a turntable, a cross-slide or a rotator, then no only is the operating cycle the most rapid, because simplest, but also the alignment of all tool components is best assured.

It is hardly necessary to spell out here how such alignments may be reduced to practice. A mold designer copes with similar problems every day and he will, therefore, design a parison mold with confidence, so long as he is made aware of the problem.

The last element of the parison mold, the neckring (or rim forming tool), calls for hardly any comment beyond what has already been made. Whether the neckring is parted or not depends on whether the neck may be released from an unparted tool. Thus, threaded bottle necks call for parted neckrings and cup-rims do not. In either case, there is nothing noteworthy here in comparison with any other injection mold component, except for the features that relate to overall tool alignment according to the preceding discussion.

PARISON MOLD TEMPERATURE

The parison mold is to produce a parison which is in "blowable" condition,

*See U.S. Patent 3,029,468 and Patents Pending

meaning that it can, after transfer into a blow mold, expand into the shape determined by that mold, acquire an acceptable outside surface therein and exhibit a wall thickness distribution after expansion which conforms to the intended container design.

As previously explained, whether this occurs or not, depends on two things - the parison dimensions and its temperature distribution, assuming that gross materials defects are not involved, such as faulty plastification, lack of melt homogeneity, or uncontrolled parison cavity packing.

In principle, any blown wall thickness distribution could be obtained from a parison of one and the same temperature throughout by appropriate choice of parison wall thickness alone; and also, from a parison of constant wall thickness, by corresponding choice of the temperature profile.

It is, however, clearly impossible to devise a reasonable process in which the temperature distribution in the parison is either controllable at will or one in which the temperature is constant throughout. It is necessary, therefore, to accept, as is always the case in injection molding and like processes, whatever ultimate temperature profile turns out to be the "steady state pattern", establishing itself by interaction of the best available control of melt temperature and the practically attainable temperature control by heat exchange in the several parison mold components. By no means will that pattern amount to uniform temperature. In a typical case, hot plastics will enter at the bottom of the parison, flow upward along the core and body mold over a fair distance, until it reaches the neck, or rim, the last amount of entering plastics remaining at the bottom. The neck has to start cooling immediately, if it is to be ready at the end of the cycle. The body, including the region next to the vigorously cooled neck, as well as the hot sprue area, has to reach the temperature best suited for blowing which is lower than the melt temperature. Clearly, a uniform temperature could be attained only at the expense of more time than any economically feasible process can tolerate. Therefore, over the full extent of the parison, and, to result in consistent product, consistently controlled. Control of the dimensions hinges on the alignment of the tool components, as heretofore discussed. It remains to be shown how the temperature profile may best be influenced, given a melt temperature determined by the injection unit.

It has been noted that temperature and wall thicknesses influence behavior of the parison in blowing. There is one additional factor to be considered - shape. Specifically, in a more or less cylindrical viscous or visco-elastic body exposed to internal pressure, radial expansion and wall thickness deformation will be reasonably predictable and consistent. If that cylindrical body has a closed end, the center thereof will, according to theory, not move, nor deform, and the transitional area between the end and the cylindrical portions will deform in accordance with the results of somewhat complex computations. As a pratical matter, in a parison made by best available rather than theoretical means, there is no way to say where there is a "bottom center at constant temperature". In fact, the central region of the parison bottom, as injected, tends to be unstable, and, to all appearances, fortuitously mobile. It will shift once to this side, then to the other, it will thin out, gather a welt, or burst in blowing. The only way to avoid such unpredictable behavior is to cool the parison bottom, thereby rendering it immobile and undeformable while the rest of the parison expands in blowing.

The other end of the parison is the neck, contained within the neckring. Obviously, the neck does not need to be maintained in deformable condition, because it is not to be shaped by blowing. At the same time, in most commercially specified containers, the neck is substantially thicker than the body wall, for reasons of container design. Thus, if it is to be cooled in time to catch up with the rest of

the container at the end of the molding cycle, it has to be cooled longer. Starting to cool it as soon as the neckring is filled is usually none too soon.

Thus, for pratical reasons, the parison is to be vigorously cooled at both ends, while the region in between remains at elevated temperature.

Accordingly, the bottom of the parison mold and the neckring must be provided with cooling, while the body mold is heated. If the parison cavity is unparted, the cooling of the bottom must still be accomplished alongside of heating the rest, by accommodating a cooling water circuit in it, and by providing insulation, or at least the minimum of contact between a separate bottom plate and the body to which it may be permanently attached. In a parted parison mold, the previously indicated alignment considerations spell out the need for a separate bottom plate and sprue bushing, unattached to the body mold halves. In such a mold, it is quite easy to separate the temperature control of the bottom from that of the body. The bottom may be cooled by chilled water, while the body may be heated by oil.

Injection molds in which temperature gradients must be maintained consistently are not unknown to the injection mold designer. Nothing unexpected is encountered in a parison mold, so long as it is recognized what to cool (neck and bottom) and what to heat (body); and what the necessary range of temperature is. Chilled water is used for the mold components that are to be cooled and heat-transfer oil between 200°F and 250°F (occasionally even higher) is used for body mold cooling.

Heating of the body mold, is incidentally, not the sole purpose of the heat transfer medium. The body mold should, in most cases, be held at the same temperature; yet, the plastics acquires a longitudinal temperature gradient immediately after injection.

Accordingly, the heating medium functions to equalize the parison body temperature, which is the reason for recommending the use of a heat transfer fluid, rather than, say, electric heaters.

The mechanical means to accommodate these several cooling and heating circuits present no unusual problem. In a parted, wedge locked body mold, access for the hot oil lines may give the designer some pause for thought at times, depending on how crowded the rest of the assembly turns out to be. But, as with most cats, there is usually some way to skin it.

The worst predicament the designer faces respecting temperature control derives from the blow core which influences the parison in fact more than any other part of the mold assembly, since it is an "inside" part onto which the parison tends to shrink, thereby producing the best thermal contact with any of the mold components.

Left to itself, the blow core would gradually become heated to near the melt temperature at the tip, in the course of numerous succeeding cycles, while being cooled near the blow slot by expansion of the blow air through that slot every time a parison is being expanded in the blow mold. To maintain the necessary temperature profile in the parison and to approximate equalization oftemperature, the tip must be cooled and the opposite end heated.

In a stubby, short core, as for example in a cup or jar mold, hot oil circulation in well known ways is very adequate for the intended purpose, provided that the oil channels are effectively close to the core surface all over. In fact, instead of channels, a hollow core-cap over an oil pool is recommended, making sure to separate the oil from the blow air, which must also be brought into the core.

In long, slender cores, temperature control by means of heat transfer fluid is very difficult to accomplish effectively. One needs only to visualize a 10" to 12" long core, with some additional length beyond the actual core, for alignment, attachment and the like, all with a diameter close to 3/4", to grasp the unpleasantness attached to introducing significant quantities of heated oil from end to end, in two separated channels, while leaving the mechanical integrity of the core the least affected, so as not to aggravate misalignment, should it tend to occur.

More than any other single cause, the problem of temperature control in the blow core is probably responsible for injection blow molding having been relegated, for a long time, to producing only containers, such as jars and short bottles, in which long, slender blow cores were not needed.

The solution is as simple as it is unusual. Instead of attempting to influence the core temperature from the inside, temperature conditioning is accomplished from outside the blow core. This is achieved in the following manner.*

Bearing in mind that the core tends to overheat at the tip (where the parison should be cold) and tends to undercool at the blow slot (which is at the end of a thin flow-path for the plastics), an electric cartridge heater is inserted near the blow slot, providing approximately the same heat input as the plastics does upon impingement against the tip. Thus, instead of becoming hot at one end and cold at the other, the core would become uniformly overheated, unless still another thing were done to it, namely, appropriate external cooling over its entire length.

The process of injection blow molding includes the blowing step, of course. During that step, the blow core will have fulfilled its function by admitting blow air at the beginning. After that, it may be extracted from the blown container, provided that pressure is maintained in the container while it cools in the blow mold, so as to maintain it in contact with the mold wall for effective heat transfer. By virtue of suitable machine design, pressure may be so maintained and the blow core accordingly extracted immediately after having admitted blow-air into the parison.

Several benefits accrue in this procedure. For one thing, the core is removed from the neck before most of the shrinkage occurs, thereby minimizing residual stresses. For another, the time needed to extract the core overlaps cooling of the bottle, resulting in a reduced overall operating cycle. Most of all, and of immediate importance in the present context, the cooling dwell of the bottle in the blow mold provides the time in which the blow core temperature may be restored, by the simple expedient of blowing air (or, at times, moist air) against it, without the penalty of an increased work-cycle or a larger number of tools.

External blow core cooling is at times applied as the last thing before inserting the core into the parison mold, in machines that do not provide for overlap of core extraction and cooling in the blow mold. The principle in these more primitive machines is the same - the core design is not affected, only the overall operating efficiency.

With external cooling, the blow core becomes very simple indeed - no more than a solid pin at the end of a valve stem and a poppet seat.

Without external cooling (combined with heating of the blow-slot region), core pins, to be practical, are badly limited in length. The mechanical requirements are such that materials other than tool steel are hardly practical for cores of any appreciable length and, therefore, materials of much better conductivity are of little help, except for short cores.

*patents applied for

Whether external cooling of blow cores is available or not depends on the machine to be used, not on the tool design. If the tool designer does not want to be exposed to a disgruntled customer, he had better avoid injection blow molding tools for articles requiring cores under 1" in diameter with a length approaching 5", unless he knows that the customer's equipment is capable of external core cooling. In that case, the limit in size is given not by consideration of temperature control, but by the likelihood of core deflection, as previously indicated.

THE BLOW MOLD

No considerations apply to the body structure of the blow mold in injection blow molding that would not hold for an extrusion blow mold. Obviously, the elements present in extrusion blow molds for pinching-off the parison and for flash removal, are omitted, since there is no flash, nor is it necessary to weld together any part of the parison.

Because the neck (or rim) is injected into the neckring, it requires no blowing and, hence, no forming tool as part of the blow-mold assembly. Suitable space and alignment means must, of course, be provided at the end of the blow-mold to receive the neckring, as transferred, together with the blow core, from the parison mold.

While this is the normal procedure, there is nothing in the way of producing a blown, rather than injection molded neck-finish, or a finish which is part injection molded and part blown. There are neck designs which cannot be made in any other way than by injection, as for example a neck, threaded on the outside, with a fitment lock (ribs or cam) on the inside. Other finishes, in turn, must be blown to be made at all, as when the neck exhibits an internal undercut, say the inward turned lip of a milk bottle. And finally, the combination of the two may be called for, to result in a neck finish most of which is accurately injection molded, but which also has a region from which a core could not be withdrawn. In the vast majority of cases, however, the injection molded neck is used.

The neckring into which the finish is injected must always remain on the neck, until blowing and cooling in the blow mold are completed and the finished article released. It is not possible, as a practical matter, to release the neck from a tool that remains attached to the parison mold and to reposition it flawlessly into another tool which is part of the blow mold, except at the expense of a sufficient cooling dwell before such repositioning, to set the neck completely. Not only is such a cooling dwell wasteful; it affects the temperature distribution of the parison and increases the difficulty of controlling it. This is a problem with which the machine designer must cope, rather than the tool designer. The latter is advised not to provide for an injection molded finish, unless the machine in which the tool-set is to be used includes means to transport the neck ring to the blow mold.

Positioning of the parison before blowing and its alignment should start with the blow core center line. If properly injection-molded, the parison is aligned with the blow core and the blow core with the neckring during the transfer from the parison mold to the blow mold. It is, therefore, sufficient to locate the blow mold in relation to the neckring by closing it against a suitable outside face or diameter of the neckring. The free end of the parison is close to, but not touching, the bottom of the blow mold, as the latter closes.

The blow core is strictly speaking, not a tool component in the blowing step, but merely a valve. The following considerations may be borne in mind regarding it, in its function during blowing.

The blow slot should be placed in a location which will eliminate, or minimize the hazard of impinging the initial blow-air blast against a hot area of the parison. For that reason, the best location for the blow-slot is near the neck, away from the bottom center. Beyond this general rule, the exact location of the slot is not very critical.

The blow-slot must open adequately to admit all the pressure-air needed to fill the shape and to build up the pressure therein in a small fraction of a second. As the parison expands, its walls become thinner and, therefore, cool faster than before. If the expansion is slow, the expanding wall may cool sufficiently to lose some of its ability to expand and to conform exactly to the detail of the blow mold wall. Actuation of the blow core as a valve is a function of the machine over which the tool designer has little control. He should be aware of the way in which the blow core is to be opened and closed in any given instance, if for no other reason than to counter unjust criticism. If the blow-slot actuation is inadequate, the slot may become clogged during injection, or, never open enough in blowing (or both). For example, if the machine provides a spring to close the blow slot in a core which is not supported at the free end, there will be a tendency for clogging with polyethylene which will penetrate a gap which may be as small as 0.0005". In an unsupported core, the entering plastics may deflect the tip which in turn would bend the core stem at the slot, producing a minute gap, unless there is an exceptionally long, tight guide preventing deflection of the stem portion of the core relative to the sleeve portion. (There is seldom room for sufficient bearing length for this.) The best core actuator is one in which both closing and opening are positive, as for example by way of a gear or a rack and pinion. Next best, closing is accomplished with a wedge and opening by spring, or by the pressure air itself. The most reliable - and simplest - actuation is reserved for machines that permit moving the blow core into engagement with the parison mold bottom. Here, the locking force applied to the blow core is used to close the blow slot and to keep it closed during injection; and the blow air is used to open the slot.

One of theever-recurring hopes is to use a porous blow core. This has proven to be impractical, because any porosity that is fine enough to prevent clogging of the pores is too dense for sufficient air flow during blowing.

DIMENSIONS AND MATERIALS

Dimensions and tolerances are taken into account the same way as in injection molding and extrusion blow molding, respectively. Mold shrinkage is allowed for in the neckring, but not in the parison mold cavity. The blow mold must allow for shrinkage, in an amount which only experience with a given machine will determine.

The materials from which the several tool components are made are not unusual. The parison mold is usually tool steel, as are the neckring and the blow core. The loss in rigidity and durability of the blow core, when made of anything but steel, is greater than the possible advantage due to improved heat conductivity which other materials could provide. Much better to design the core so that internal or external temperature control is rendered possible than to rely on equalization or adjustment of temperature by the conductivity. In fact, as previously discussed, a temperature gradient is usually necessary, for successful blowing. It is harder to establish and to maintain in a good conductor than in a somewhat poorer one. Thus, cooling of the neckring, if conducted into the central region of the blow core by way of the mechanical assembly, would tend to cool the parison unduly.

The blow mold may be made of iron (or steel), of aluminum alloy or from the

usual zinc alloy, except at the neckring seat which must be made of steel, to assure good alignment and to minimize wear.

CONCLUSIONS

The designer of injection blow molding tools needs to use no more than his knowledge of conventional injection molds and blow molds, to succeed, provided that he takes the process interrelations of the injection and blowing steps into account. He is well advised to study the overall function of the machine into which his tool is to fit, and not only platen dimensions, stokes and the like.

Because temperature control is no less important than are the dimensions, close attention must be allotted to the design of fluid channels and to the thermal separation of the several tool sections which must be maintained at different temperatures.

The tool designer should encourage and support standardization of tool components, in the interest of cost. For example, a reasonable range of container shapes may be made using the same blow core, neckring and parison mold, varying the blow mold only. The range is extended when all the container shapes are added for which only the blow core length has to be changed.

Accordingly, the tool designer may influence not only the product quality - which he always does - but also, the overall applicability of the injection blow molding process.

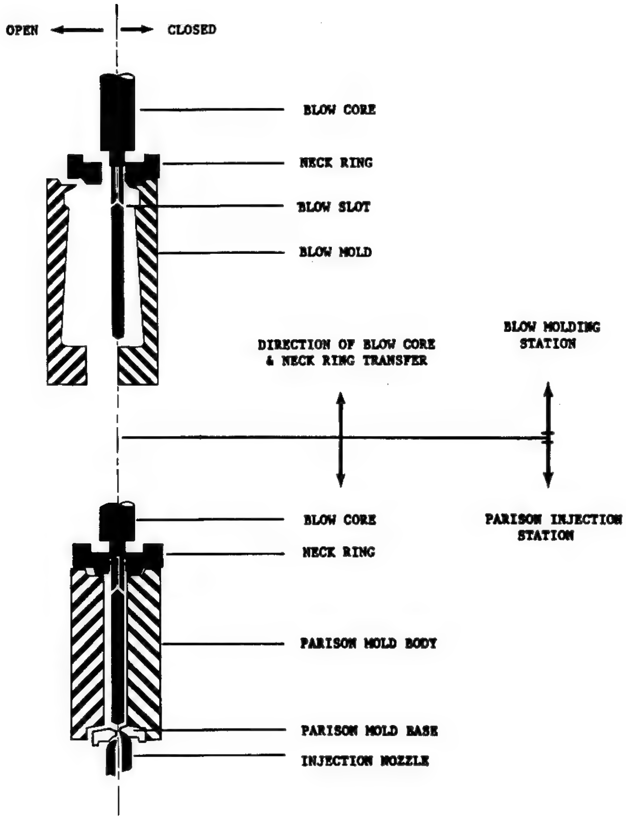

FIGURE 1

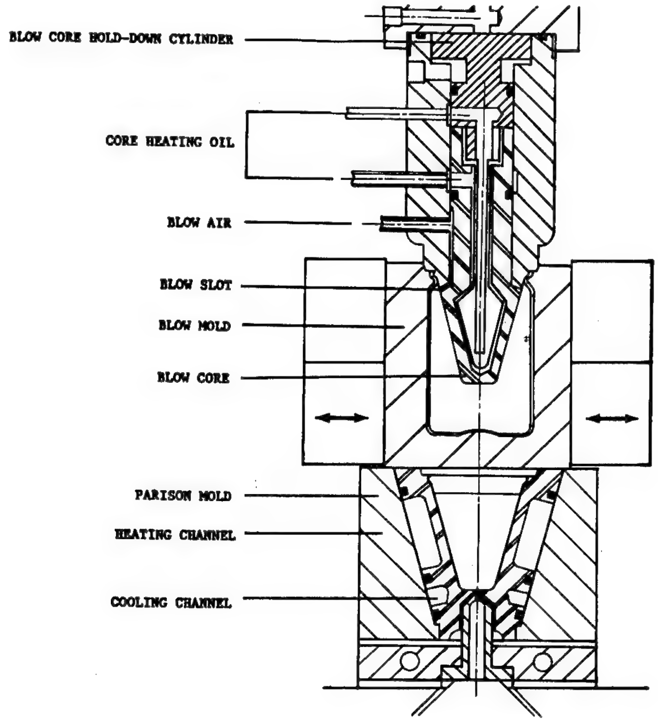

FIGURE 2: Tool-set for Wide-mouth Ware With Single-piece Parison Mold.

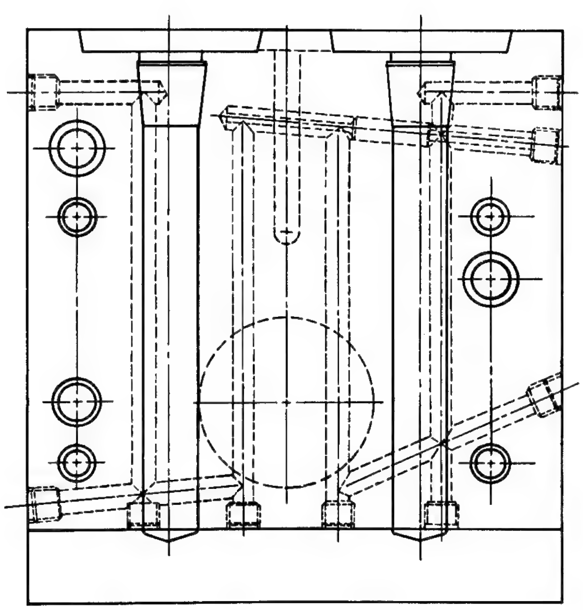

FIGURE 3A: Mold-set for Narrow-neck Ware: The Parison Mold

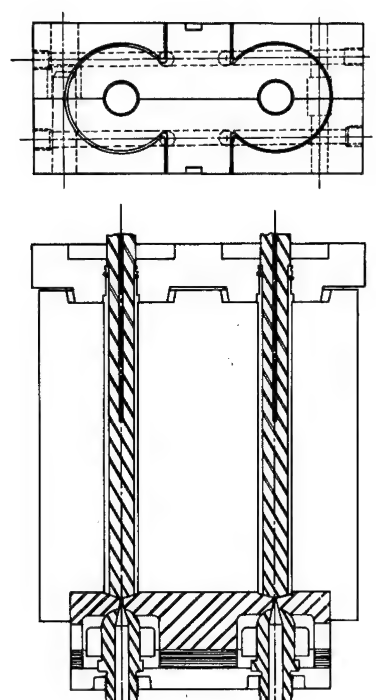

FIGURE 3A: Mold-set for Narrow-neck Ware: The Parison Mold

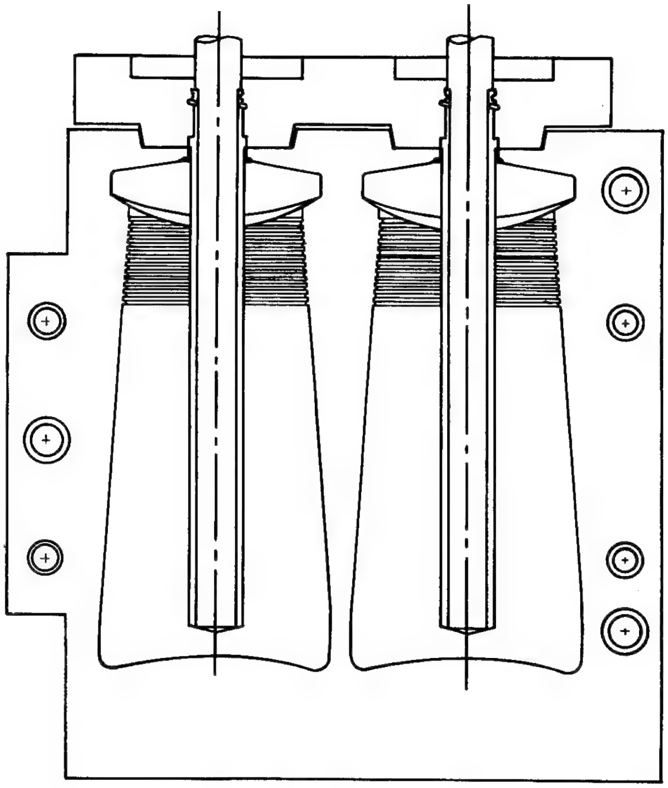

FIGURE 3B: Mold-set for Narrow-neck Ware: The Blow Mold

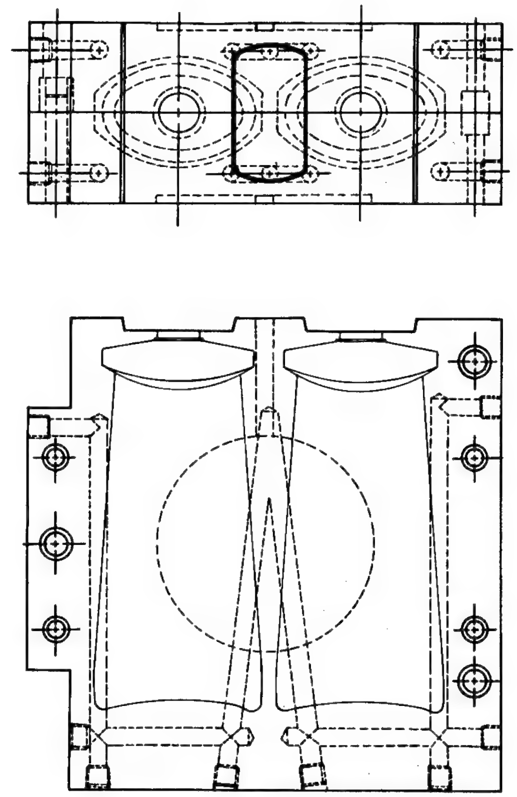

FIGURE 3B: Mold-set for Narrow-neck Ware: The Blow Mold

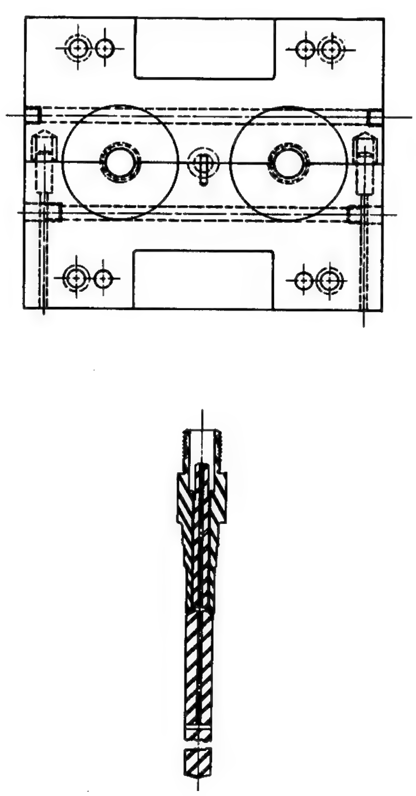

FIGURE 3C: Mold-set for Narrow-neck Ware: The Neck Ring and Blow Core

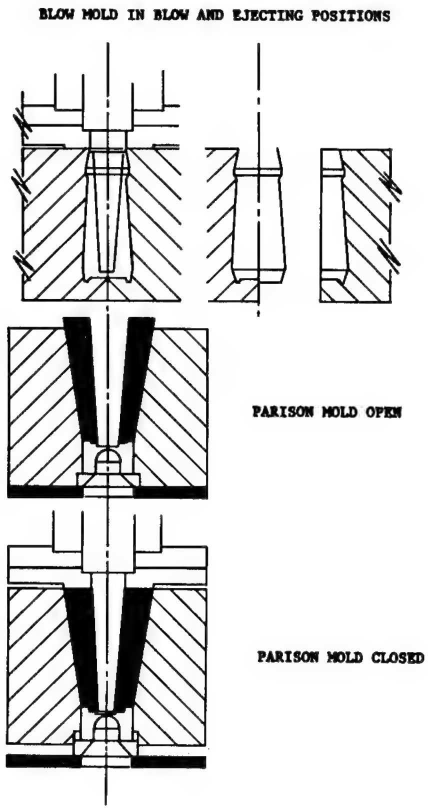

FIGURE 4: Tool-set for Wide-mouth Ware, With Parted Parison Mold

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OUTLINE

A NEW CONCEPT OF THE CAUSES OF PITTING IN POLISHING MOLDS

William Young

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1. Review of fundamental rules which are too often forgotten by the moldmaker, and the violation of which leads to trouble.

2. Types of surface conditions which results - hairline cracks, "orange peel", pitting.

3. Slides illustrating what happens during polishing and overpolishing.

4. Causes for the phenomena demonstrated - including the development of forces exceeding the tensile strength of the steel itself.

5. Why the problems experienced in polishing are more pronounced in soft and semi-hard steels than in very hard, and nitrided molds.

9579-6

PROPERTIES AND PROBLEMS IN PLASTICS MOLD MATERIALS

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INTRODUCTION

The materials used for plastics molding must obviously have certain combinations of properties which will allow them to give optimum performance in terms of die life for the production of parts of sufficient quality for the specific application of the plastics part. This statement, of course, implys a foreknowledge of the number of plastics parts to be produced from a given mold or set of molds since steels which would exhibit mold deterioration in long production runs would certainly be suitable for application when a small number of parts are to be produced. In this discussion we will disregard this consideration and confine our thinking to the property requirements of materials for long production campaigns where conditions will be most severe.

Let us first examine the conditions under which plastics molds operate, attempt to define the limits of these conditions where possible and then examine the effects of some of these conditions on various materials.

TEMPERATURE

In dealing with materials for plastics molding or forming, we must be concerned with the maximum temperature experienced by any part of the die rather than by the so-called mold or die temperature. For example, in injection molding, which is essentially a pressure casting operation, the surface of the mold will instantaneously see a temperature equal to that of the heated resin being forced into it. Since the resin hardens by cooling, the mold surface experiences a cyclic temperature variation between the mold temperature and the resin temperature. For two reasons, the surface temperature of the mold may actually exceed the resin molding temperature. Frictional heating developed as the resin flows past the mold surface can cause marked temperature increases while adiabatic heating of the air pocket in an improperly vented mold can easily produce temperatures above those ofthe resin. Fortunately, in plastics molding, these two effects are largely self-controlling since they will produce burn marks on the plastics parts if the temperature produced exceeds the resin temperature significantly. New resins are continually being developed which lend themselves to the injection molding process and which have higher molding temperatures. Resin temperatures in the range 650-700°F are not unknown at the present time. With higher molding temperatures, the temperature range through which the surface of mold materials will cycle becomes greater and a possibility exists that the failure mechanism known as thermal fatigue and commonly found in the die casting industry will be experienced.

In compression molding and extrusion dies this temperature cycling is not nearly so prevalent. Here, mold materials must be able to maintain the necessary physical properties at the forming temperatures to perform their functions. Today resin molding temperatures are not so high that the high hardness steels normally designed for cold work applications cannot be applied in most instances. At the low end of the molding temperature range, carbon steels such as carburized P1 hobbing grade can be used. As higher temperatures in this range are reached, higher alloy content is necessary to resist the tempering effect of sustained or cyclic temperatures approaching 700°F.

STRENGTH

The main function of strength in plastics mold materials is to resist deformation by the pressure of molding or extrusion. Pressures for injection molding and extrusion are normally below 30,000 psi, while compression molding pressures may range somewhat higher. Although at times a molded part may become caught as the dies close thus subjecting a small part of the die to high pressure, when one realizes that steels with a hardness of only Rockwell C 50 will have a compressive yield strength well over 200,000 psi, it can be seen that resistance yielding under pressure will become a significant problem only with carburized die materials having low core hardness.

ABRASION RESISTANCE

While the pure viscous liquid resins forced into a mold in the injection molding process produce insignificant abrasive wear and the powdered resins used for compression molding are only slightly abrasive to mold materials, the addition of hard and refractory filler materials to these resins has created significant abrasive wear. Fillers of asbestos, mica and glass, metal or ceramic fibers, while markedly improving the strength properties of resins, will also produce severely abrasive conditions for mold materials to withstand.

Most abrasion resistant materials combine two structural effects to obtain their wear properties. The first of these involves a high hardness as measured by the large area penetration resistance tests exemplified by the common Brinell or Rockwell scales. Whether this high hardness is obtained by heat treatment, cold working or by some other method, is relatively insignificant as long as a high degree of penetration resistance is achieved. Further improvement in abrasion resistance can be achieved by suspending in this hard matrix even harder and more abrasion resistant particles, usually metal carbides, to produce an effect much the same as that obtained when gravel is used to improve the abrasion resistance of concrete. In addition to these structural possibilities, various surface treatments such as nitriding or chromium plating can be applied to improve abrasion resistance of the working areas of plastics molding dies.

A major problem in development and application of mold materials lies in trying to define the degree of abrasion or wear resistance required for forming the multiplicity of resin compositions available either by themselves or in the various possible combinations with filler materials. So far as we have been able to determine, no generally accepted test is used to describe the abrasive qualities of various resin-filler combinations. In the absence of a bench test, useful information on the abrasive properties of resin-filler combinations could be obtained by collecting a large body of production data from many molders which could then be subjected to statistical analysis. With sufficient data, I am sure that a rather complete picture of the abrasion resistance requirements for molding various

plastics types could be developed.

CORROSION RESISTANCE

The corrosion resistance requirements for mold materials are even more difficult to define than the requirements for abrasion resistance. Presumably, if each resin could be molded at precisely its optimum temperature, little or no degradation would occur and the need for corrosion resistance would be minimized. Practically, these optimum conditions may be impossible for a number of reasons.

A general understanding of the nature of corrosion resistance is necessary before attacking specific problems. Materials described as corrosion resistant do not exhibit the same degree of resistance to attack when exposed to all corrosive media. For this reason, any description of corrosion resistance must include both the condition of the material and a rather complete analysis of the corrosion conditions including corrosive medium, concentration, temperature, surrounding atmosphere and contact time.

A case in point is found in the polyvinyl chloride resins which literature references indicate to be relatively unstable under temperature application and to suffer degradation which produces hydrochloric acid or hydrogen chloride gas. Stainless steels and chromium plating show rather poor resistance to attack by hydrochloric acid and hydrogen chloride. The only materials known to show good corrosion resistance to even dilute solutions of hydrochloric acid or to hydrogen chloride gas are tantalum metal and certain of the nickel base cast alloys such as Hastalloy B. We are not aware that these materials are presently being used in the molding or extrusion of polyvinyl chloride resins and thus it must be assumed that some other factor is modifying the corrosion conditions so that they are not as severe as would be indicated by the simple description.

SUMMARY

are discussed

To sum up this discussion, we have looked at some of the conditions to which plastics mold materials are subjected and have found that in several cases these conditions are poorly defined. This lack of definition mitigates against both the optimum selection of mold materials which are presently available and the development of materials specifically designed to withstand the conditions encountered in plastics molding and extrusion. The producers of specialty alloys have the tools available to develop such materials if the parameters can be more precisely defined.

The Society of Plastics Engineers would seem a logical source for this information and, therefore, as a representative of the producers of mold materials, I would like to challenge you with the need for a systematic definition of property requirements. This is a job which your organization can do. Although the task is large, the rewards in terms of improved die performance would certainly be of commensurate value today and will grow in value with the technological and economic expansion of the plastics industry.

9579-1

NEW STEEL MAKING PROCESS AND ALLOYS FOR THE PLASTICS MOLDING INDUSTRY

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INTRODUCTION

Technological developments in the manufacture of steel which is used for molding plastics have progressed at rapid rates. The tremendous growth rate of the plastics industry has resulted in the development of many new varieties of plastics. These plastics have in turn created some heavy demands on the steel used for forming or molding these new materials.

Steel quality as it pertains to mold making, is affected mainly by segregation, inclusions, and gas content. Rigid control of these factors is required for maintaining a high level of mold quality.

The need for new and improved steels for plastics molding became quite prominent during the early 1960s. Fortunately, in the decade prior to 1960, the steel industry had been going through a technological change whereby vacuum melting came into being.

Vacuum melting provided the means for significantly improving the quality of the standard compositions used for molds. In addition, it enabled more complex alloys to be made readily available.

VACUUM DEGASSING

The first new process used in attempting to improve steel quality was vacuum degassing. In this process the steel was melted using standard airmelt practises; however, the final step involved casting or teeming the molten metal through a vacuum chamber into an ingot mold. The main function of vacuum degassing was to reduce the gas content of molten steel. Gases normally present in steel are oxygen, hydrogen and nitrogen.

Oxygen combines with various elements to form oxides which are present in the solid steel as inclusions. These inclusions, more commonly referred to as dirt, create difficulty when the moldmaker attempts to put a high lustre or finish on the cavity of the mold. These oxide particles can be present in the form of stringers or they may be present in forms described as globular masses. Regardless of the form, these inclusions are detrimental to good mold making practices.

Hydrogen in steel generally does not combine with other elements. As a result,

hydrogen tends to produce holes or cavities in steel. The ultimate result of a high hydrogen content would be excessive microscopic holes in the steel known as pin holes. Obviously the presence of pin holes in a mold causes extreme difficulty.

Nitrogen performs in a manner similar to that of hydrogen; however, nitrogen also forms various nitride compounds such as titanium nitride or zirconium nitride. These nitrides are readily observed under a microscope at 100 magnifications, and their appearance is generally in the form of stringers or areas of massive particles. As with oxides, nitrides can cause difficulty when trying to achieve a high polish on a mold cavity.

Vacuum degassing was found to produce a significant improvement in material quality through the reduction of inclusions and gas content. These improvements however, were exceeded considerably when the material was subjected to a full vacuum melting process. Vacuum melting as it exists today is conducted in two production type furnaces - induction vacuum melting and vacuum arc melting.

VACUUM INDUCTION MELTING

Vacuum induction melting consists of melting in an induction furnace enclosed in an evacuated chamber. The charge is made up of virgin raw materials and/or vacuum melted revert scrap. One or more preheated ingot molds are introduced into the furnace by means of a mold lock. After the required analysis and proper pouring temperatures are attained, the induction unit is tilted and the ingots are poured. Samples from the melt may be taken at any time during the melting to determine the extent of purification or pretap analysis. If necessary, corrective additions are made via a charging lock.

Vacuum induction melting is used primarily for melting complex superalloys. The composition of these alloys must be controlled very closely in order to attain the desired mechanical properties. Vacuum induction melting is a flexible process as far as composition control is concerned. That is, there is flexibility in the selection of raw materials and no metallic deoxidizers such as silicon and manganese are required. In addition, molten metal can be sampled and analyzed and corrective additions made if necessary. An added benefit is the fact that losses of volatile elements are small and uniform from heat to heat.

All of this makes possible the production of high purity metals with low gas and carbon content and alloys with very low contents of trace elements as well as extremely low silicon and manganese contents. Alloys with narrow specification ranges for highly reactive elements are controlled quite readily in this type of melting.

This process has one major limitation over its competitor in that the quantities melted in a vacuum induction furnace are generally limited to approximately 10,000# of steel. Consumable arc melting is done in furnaces capable of producing ingots as large as 60" in diameter and weighing approximately 50,000 pounds.

CONSUMABLE ELECTRODE VACUUM ARC REMELTING

Vacuum arc melting consists primarily of remelting airmelted electrodes in an evacuated chamber. During melting the metal transfers from the electrode to the mold as a uniform flow of super heated droplets and these collect to form a molten pool. The size and shape of the pool is a direct function of the melting rate used. It has been found that the melting rate required to produce the ultimate in

quality for any given grade will vary according to the composition of that grade. As the electrode is consumed, the ingot progressively solidifies from the bottom upwards. As a result, center porosity and segregation normally found in conventionally cast ingots are minimized by the vacuum arc process.

Vacuum arc melting has the task of removing the gases and inclusions present in the electrode. The oxides break up under the low pressure and high temperatures. The gas portion is pumped out while the alloying elements unite with the metal. Inclusions rejected during the cooling are relocated so that they can be discarded during processing. Large stable inclusions float to the top of the molten pool where they can be cropped off from the ingot. Other inclusions are trapped in the fast freezing metal at the ingot wall where they can be subsequently turned off. Only tiny inclusions that float out slowly get caught in the ingot.

The chemical composition generally is not affected greatly by vacuum arc melting except for the volatile elements present in the analysis. This is generally restricted to one element, namely, manganese. The manganese loss is readily corrected by air melting electrode stock to a higher manganese level than that required by the specification analysis. This allows for vaporization losses during vacuum arc remelting and the final product then is within the required chemical range.

As with vacuum induction melting, vacuum consumable electrode arc melting results in a lowered gas and inclusion content. The additional benefit derived from consumable melting, which is not attained when vacuum induction melting, is a controlled rate of solidification. This controlled rate of solidification results in uniformity in an ingot from bottom to top and center to outer periphery. Modern technology of mold making for new and improved plastics requires that the mold be extremely uniform. Mold uniformity then enables the achievement of a plastics molded part with excellent consistency.

STEELS FOR MOLDING PLASTICS

Plastics molding is done in molds made from one of two basic types of tool steel. Table I lists the composition of AISI P-20 steel which is most popular in mold shops today. This steel is purchased in a prehardened condition. The steel has been heat treated to a hardness and strength deemed most appropriate for long mold life and compatible with easy machining characteristics. When a mold builder is converting a block of steel into a mold, his primary concern is the uniformity of machinability and polishability of the steel from one end to the other. In addition, he does not want to encounter any porosity in the steel as he traverses the various areas while producing the mold configuration. Over the years, steel companies have attempted to hold segregation and porosity to a minimum. Actually, this has been accomplished with a very high degree of satisfaction and achievement. However, there still are occasions when a faulty piece of steel is encountered. The function of vacuum melting is to completely eliminate this type of faulty steel. In addition the vacuum melted steel, because of its lower inclusion content, coupled with the uniform macro etch characteristics achieved by consumable melting, now yield a superior forged product from which to make a mold. In other words, making P-20 utilizing the consumable vacuum arc melting practice is considered the ultimate form of this particular steel.

The effect of vacuum melting on the cleanliness of P-20 steel is illustrated in Tables II and III. Steels having a cleanliness rating as illustrated in Table III readily lend themselves to a highly polished lustre.

Other analyses used for making molds when molding plastics are the AISI A-6

and A-2 varieties of tool steel. The composition of these steels is also shown in Table I. A-2 and A-6, as noted in Table I, have a much higher carbon content than is present in P-20. Since carbon content determines the attainable hardness in steel, obviously A-2 and A-6 have the ability to be heat treated to a much higher hardness and strength than can be achieved with P-20. In addition, A-2 and A-6 have present in their micro structures complex carbides which contribute to the abrasion resistance of this material. In other words, these two steels can withstand the abrasive action of hot plastics much more readily than can P-20.

A-2 and A-6 are known as air hardening type steels and this family of tool steel has the ability to harden all the way through on large mold sections. Quite often, this characteristic of hardening throughout the cross section is undesirable due to lack of adequate toughness. In these applications, P-20 is used after its surface carbon content is increased by a carburizing treatment. P-20 has a nominal carbon content of .35 and the carbon content at the surface is increased to a value greater than 1% through this carburizing treatment. The end result is a mold with a high carbon content, high hardness, high abrasion resistance and a relatively soft tough core.

Unfortunately, the technological developments concerning consumable vacuum arc remelting are such that this practice is most beneficial when applied to steels whose carbon content is less than .75% carbon. In other words, higher carbon materials such as A-2 and A-6 do not lend themselves to this type of melting, except in relatively small ingots. Vacuum consumable arc melting tends to aggravate the carbide segregation problem in the high carbon steels. As a result, vacuum arc melting is not necessarily a beneficial treatment to be used with all steels available today. The advantages gained by a reduced inclusion content are offset by an increase in carbide segregation.

NEW MOLD STEELS

The development of these vacuum melting techniques has given rise to new and improved compositions which make excellent mold steel. One such composition is called maraging steel and is finding extensive use in plastics molding applications. The analysis of maraging steel is given in Table IV. The metallurgical characteristics of this material differ from the normal martensitic tool steels. Maraging steel is supplied in the annealed condition at a hardness of approximately 30 Rockwell C. In this condition, the material is relatively easy to machine. Upon converting the block of steel to the final mold size and shape, it can be heat treated very simply by subjecting the mold to a treatment of 4 to 10 hours at a temperature of 900°F. This treatment produces an increase in hardness of approximately 20 points Rockwell C yielding a final hardness of 50-54 Rockwell C. This increase in hardness is achieved without any significant change in size.

The relative freedom of maraging steel from radical size changes is outstanding characteristic of this material. In addition, it has the ability to be polished to an extremely desirable surface lustre.

It should be pointed out that even though this material contains 18.00% nickel, it is not a stainless steel, since no chromium is present. Since some degree of corrosion resistance is required for successfully molding certain of the new plastics, experiments with new compositions of mold steel are currently being made. A new stainless maraging steel which has shown great promise is listed in Table IV.

Other steels are also being tried for various plastics molding applications.

To date, no one composition stands out as a possible successor to P-20, with the exception of the maraging steel. The maraging steel, however, has the disadvantage of a comparatively high cost. To date, many molders have found the benefits gained from using maraging steel more than justify its high cost.

ECONOMICS OF VACUUM MELTED STEEL

The economic situation concerning vacuum melting needs some clarification because of its confusing past history. Initially, when the two vacuum melting techniques first came into being, a nominal charge of $1.00/pound premium was placed on the product of the consumable vacuum arc furnace and a nominal charge of $2.00 premium was placed on the product of vacuum induction melting. Vacuum arc melted materials were found to be better suited for tooling applications than was the vacuum induction melted steel. In addition, vacuum arc melting resulted in a significant improvement in yield when converting ingot into finished product. This resulted in a reduction of the premium being charged for the various alloys. The premium today for consumable arc melted material varies with grade, from $1.00 per pound extra on some grades to no premium at all on others. Several extremely difficult to forge grades which produced very low ingot to finished product yield, were found to be readily forgeable when consumable arc melt. Their forging characteristics improved to the extent that it resulted in yields which overcame the cost of vacuum melting.

There appears to be no limit to the range of compositions that are obtainable commercially by use of these vacuum melting techniques. In addition, as technology advances in the plastics industry, the mold steel requirements will become more acute. The steel required to meet the need is either available or is in the experimental or development stage. For instance, many of the sophisticated alloys developed for the jet engine or missile and rocket industries readily lend themselves to various difficult or complex tooling applications.

In addition to vacuum melting as a means for producing a better mold steel, mold builders are making use of vacuum heat treating. Vacuum heat treating serves to enable vacuum melted steels to be treated without any surface contamination and helps keep size change or distortion to a minimum. It is not beyond the realm of possibility that a section of vacuum melted steel will be converted into a plastics mold, heat treated in a vacuum furnace, and delivered to the molder in a matter of two or three days. The technological advances in melting, heat treating and machining all offer methods for eliminating the difficulties that are common every day experiences today.

TABLE I

STEELS FOR PLASTICS MOLDING

GRADE	C	Mn	Si	Cr	Mo	V
P-20	.35	1.00	.30	1.25	.35	.15
A-6	.70	2.25	.30	1.00	1.35	—
A-2	1.00	.65	.30	5.25	1.10	.25

TABLE II

EFFECT OF VACUUM MELTING ON INCLUSION CONTENT

(Inclusion Rating - ASTM E45 - 51)

TYPE MELT	A (Sulfides)		B (Alumina)		C (Silicates)		D (Globular Oxides)	
	THIN	HEAVY	THIN	HEAVY	THIN	HEAVY	THIN	HEAVY
Air Melt	2.5	2.0	3.0	2.5	2.5	2.5	3.0	2.5
Vacuum Melt	1.5	1.0	1.0	1.0	1.0	1.0	1.5	1.0

Typical Specification Requirements

TABLE III

TYPICAL INCLUSION RATINGS FOR VACUUM MELTED P-20

SPECIMEN NO.	INCLUSION RATING							
	T	H	T	H	T	H	T	H
1	0	0	0	0	0	0	1.0	0
2	0	0	1.0	0	0	0	1.0	0
3	0	0	0	0	0	0	1.5	0
4	0	0	1.0	0	0	0	1.0	0
5	0	0	1.0	0	0	0	1.5	0
6	0	0	0	0	0	0	1.0	0

TABLE IV

NEW MOLD STEELS

(Chemistry)

GRADE	C	Mn	Si	Cr	Mo	V	Ni	Co	Ti	Al
Maraging Steel	.03	.10	.10	—	4.80	—	18.50	9.00	.60	.10
Stainless Maraging Steel	.03	.10	.10	11.50	—	—	10.00	--	.35	1.20
H-13	.35	.40	1.00	5.00	1.50	1.00	—	—	—	—

VACUUM MELTING AND MARAGING STEELS

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Once a novelty, now a tried and true production tool. This expression typifies the vacuum melting processes of today. Commercially, two basic types of vacuum melting processes are operational. These are induction melting and consumable electrode melting. A combination of the two is also employed when a product with optimum cleanliness and macrostructure quality is desired. A third vacuum refining process, termed degassing, is also predominant in steel making, but strictly speaking, is not a vacuum melting process. For this refining process, steel is air melted by standard conventional practices and tapped into a ladle in the normal manner. This ladle can then be either placed into a chamber which will be subsequently evacuated (ladle degassing) or teemed into an evacuated chamber containing either the ingot molds or a second ladle (stream degassing). The pressures associated with this refining process are generally in the range from 200 to 1000 microns. A schematic diagram illustrating the two standard vacuum melting processes compared to the standard air melt electric furnace process is shown by Figure 1. As a further comparison, Table I lists the most recent weight capabilities, compared to those in 1958[1] along with the advantages and disadvantages attributed to each vacuum process.

As illustrated by Figure 1, the problem areas causing metal contamination are decreased through the use of vacuum melting techniques, with the optimum conditions for metal cleanliness being present in the consumable electrode melting process. However, electrode quality is an extremely important and oftentime under-rated variable in consumable electrode melting. This variable is somewhat analogous to the setting-up of a computer program, i.e., garbage-in-garbage-out. It is quite evident from the data of Table I that considerable strides in vacuum melting capacity have been made during the last eight years. It would also appear that the end is not yet in sight as vacuum induction melting furnaces are moving steadily into the mills of tonnage steel producers. Although this process change is evolutionary, rather than revolutionary, it is coming at a faster rate than many realize.

Why vacuum melting? The need for a more reliable product might be an appropr-ate answer. As previously mentioned, each melting process has its advantages and disadvantages and imparts a certain degree of refinement to the molten steel. This degree of refinement can generally be translated into improved steel properties of one kind or another, but in the final analysis, material reliability is the most important criterion.

What about melting costs? Everyone is in general agreement that vacuum melting costs are higher, but melting cost is not the same as total cost. Better chemistry control and ingot quality and consequently fewer heat losses and increased yields

help to keep vacuum melting costs at a justifiable level.

With this relatively brief summation of vacuum melting today, I'll now describe the metallurgical aspects of the maraging steels and the quality improvements which have been made possible through the use of vacuum melting techniques.

What is a maraging steel: A performer of miracles, jack-of-all-trades or an everyday run-of-the-mill alloy. Depending upon who you are talking with, any one or a combination of all three. I feel the best approach to take in describing the maraging steels is by way of a comparison with the more standard alloy compositions which are generally referred to as quench and temper steels.

The nominal chemical compositions listed in Table II show the maraging steels to contain basic ingredients which are characteristic to both the high-temperature alloys and medium alloy steel systems. This particular combination of elements results in an alloy with unique metallurgical characteristics. Specifically, an alloy system which can be transformed to a 30 Rockwell C hardness martensite upon air cooling from 1500°F and finally to a 52/54 Rockwell C martensite after aging (precipitation hardening) for 3 hours at 900°F. The uniqueness of this structure transformation is readily evident when compared to the transformation is readily evident when compared to the transformation characteristics of the standard quench and temper alloy carbon steels (Figure 2).

Because of this unique metallurgical characteristic, a number of processing steps may be eliminated during the manufacture of a specific item. Figure 3 schematically illustrates the normal manufacturing operations used for a quench and temper carbon steel compared to that for the maraging alloys. In some applications, however, a deviation from the indicated processing procedure is used and an intermediate or second 1500°F solution treatment following rough machining is interjected. This extra operation effectively reduces the induced machining stresses and consequently promotes increased die life. A second alternative method for the alleviation of machining stresses is the use of a long-time 900°F aging treatment on the order of 15 hours. Either or both of these "extra" treatments have been found to give added production life to die casting dies.

Another trait, although not unique characteristic of the maraging steels is their inability to be heat treated to various hardness levels. Because the maraging steels achieve their final hardness by a precipitation hardening mechanism, analogous to the high temperature alloys, hardness control and consequently strength level is dependent upon chemical composition. The three major ultimate tensile strength levels associated with 18% Ni maraging steels are 200, 250 and 280 ksi. The principal chemistry alterations which are required for these strength variations are slight adjustments in the titanium and molybdenum contents. Inasmuch as the maraging steels are available over this wide strength range, the selection of any one type would, of course, be dependent upon the property requirements of the specific application. The graph of Figure 4 illustrates the variation in 12" square billet, transverse tensile ductility and Charpy V-notch impact strength which is associated with the maraging steels over the .2% yield strength range from approximately 250/290 ksi. As indicated by this illustration, there is a relatively direct relationship between strength and ductility, with the most noticeable spread in the data occurring in the 270/290 yield strength range. However, at cross section sizes of two inches and less, the ductility characteristics are considerably more uniform over the indicated strength range.

A slightly more detailed explanation of the heat treating characteristics of the maraging steels is now in order with a general tie-in being made to the importance of mill processing and vacuum melting as related to final properties.

Figures 5 and 6 show the effect upon final hardness of variations in solution treating temperature and aging temperatures with respect to time. Also illustrated by Figures 7 and 8 are the effects of 100 hour exposure on room temperature hardness and elevated temperature hardness data. The important metallurgical features which should be noted from the curves of Figures 5 and 6 are the stabilization of austenite after exposure in the 1200/1300°F temperature range and a rapid aging response occurring with a 900°F age. It should be pointed out here that although maximum hardness is not achieved after the accepted standard 3-hour aging period at 900 F, considerable extension of this time will promote austenite reversion. Examples of the effect of extended aging times upon mechanical properties and microstructure are shown by the data of Table III and photomicrographs of Figure 9.

The exact nature of this austenite reversion phenomenon is directly related to chemistry balance and is a primary function of alloy homogenity. Because of the chemical makeup of the maraging steels, the chemistry balance is easily upset and the alloys become segregation prone during solidification from the molten state. Segregation in this context refers to minute areas throughout the solidified metal having measurably higher individual alloy concentrations than the average body chemistry. Consequently during mill processing of the ingot, these segregate areas become compressed together and after considerable reductions will form a series of parallel striations. These striations can be made readily evident by standard polishing and etching techniques. An example of this striated structure, along with the alloy chemistry differential between the light and dark etching areas is contained in Figure 10.

This particular type of segregation can, however, be minimized by proper ingot size selection and chemistry balance. Leaner alloy compositions (i.e., 200 ksi type) also tend to be more segregation-free.

When extreme cases of alloy segregation are present, then a condition referred to as "banding" will occur (Figure 11). This condition is typified by islands of 900°F reverted austenite within the dark etching (highly alloyed) striations. In essence, this phase reversion is due to a shift in the austenite transformation temperature (Figure 1) as a result of the higher alloyed segregate. A minimization of this highly alloyed area can, however, be achieved through high temperature alloy diffusion treatments. Banding of this type is not desired in the finish product as a degradation in both strength and ductility may result.

One final, but possibly the most important, consideration in the manufacture of the maraging steels is the melting practice. Extremely close chemistry control is a pre-requisite, with low residual contents of a magnitude necessitating vacuum melting practices. An inability to obtain the desired low-residual level can result in an undesirable product which cannot be salvaged by mill processing techniques. As an example of the chemistry control necessary, a nominal carbon level of .03% was established for the maraging steels.[2] However, it was found through experience that a .01% carbon maximum, .005% carbon aim, was the desired level to obtain optimum property response. Consistently obtaining this extremely low carbon level by air melting techniques was a virtual impossibility and necessitated vacuum induction melting. The effect of melting practice upon the degree of second phase contamination (in this case titanium compounds) is readily evident by the photomicrographs of Figure 12. The degree of mechanical property degradation, which is a directly related function of second phase contamination, is listed in Table IV.

SUMMARY

The foregoing discussion has, in essence, been an attempt at familiarization

rather than one of detailed description or new metallurgical discoveries. The data presented was also of the type not normally found in brochures and is hoped will be of benefit to those interested individuals.

REFERENCES

1. Metal Progress, Staff Report on Vacuum Melting Today, August, 1958.

2. Journal of Metals, Novak, C. J. and Diran, L. M., March 1963, p. 202.

TABLE I

COMPARISON OF VACUUM REFINING AND MELTING PROCESSES

Process	Weight Capability (1958),#	Weight Capability (1966),#	Advantages and Limitations
Degassing	500,000	700,000	Low operating equipment costs. Few size limitations. No alloying possible. Less O_2 and N_2 removal. Refractory contamination.
Induction	3,000	60,000	No slag-air contamination. More use of reactive elements. Good refining ability and control. High operating cost. Refractory contamination. Regular ingot problems.
Air melt-consumable arc remelt	13,000 (26" dia.)	80,000 (60" dia.)	Improved ingot solidification No slag-air-refractory contamination. Quality depends largely on original air melt.
Induction-consumable arc remelt	3,000 (16" dia.)	60,000 (60" dia.)	Combined advantages of two vacuum processes. High cost

TABLE II

COMPARATIVE ALLOY NOMINAL CHEMISTRIES

	D6AC	Marvac 18A	H11	718
C	.48	.01 mx.	.40	.04
Si		.10 mx.	1.00	.10
Mn	.75	.10 mx.	.30	.10
P	.020	.01 mx.	.020	.01 mx.
S	.020	.0o mx.	.020	.01 mx.
Cr	1.00		5.40	19.00
Ni	.55	18.00		53.00
Co		9.00		
Cb				5.00
Mo	1.00	5.00	.85	3.00
V	.10		.50	
Ti		.60		1.00
Al				.45

TABLE III

EFFECT OF 900°F AGING TIME UPON THE MECHANICAL PROPERTIES OF THE 250 KSI GRADE OF 18% Ni MARAGING STEEL

(3" x 9" x 11" Bar Section)

Specimen Location	Aging[1] Time, hrs.	UTS, ksi	.2% Y.S., ksi	% El.	% R.A.	Avg. Charpy V Impact, ft-lbs.
Long. Trans.	3	258	249	12.0	53.7	15.0
Long. Trans.	16	278	267	10.0	48.7	12.7

[1]All samples solution treated at 1500°F, 1 hour prior to aging.

TABLE IV

EFFECT OF MELTING PRACTICE UPON LARGE BILLET TENSILE PROPERTIES

(Transverse Tests)

Air Melt Plus Vacuum Arc Remelt

12" Square

T.S., ksi	.2% Y.S., ksi	% El	% R.A.
250	240	3.5	12.0
9" Square			
250	245	4.1	15.0

Vacuum Induction Plus Vacuum Arc Remelt

12" Square

	T.S., ksi	.2% Y.S., ksi	% El	% R.A.
Top	253	240	7.5	30.0
Bottom	255	244	11.0	48.0

Melting Process	Contaminant
Electric Furnace	Air Slag Refractory
Vacuum Induction	Refractory
Vacuum Arc	Electrode

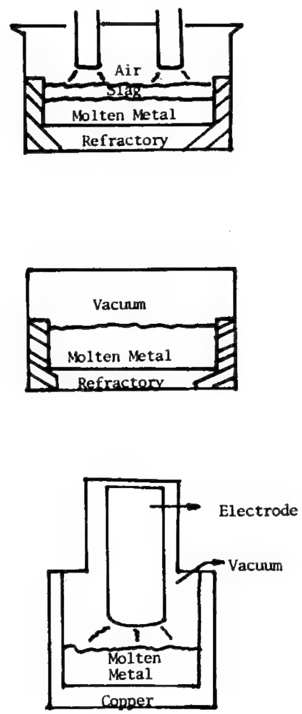


FIGURE 1: Contamination Source as Related to Melting Process

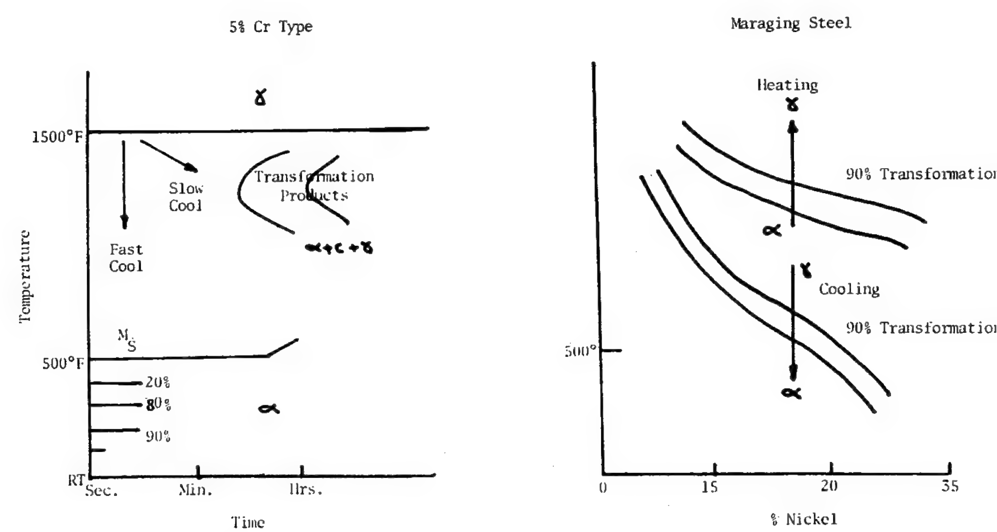


FIGURE 2: Phase Transformation Characteristics of the Maraging and 5% Chromium Die Steel Types

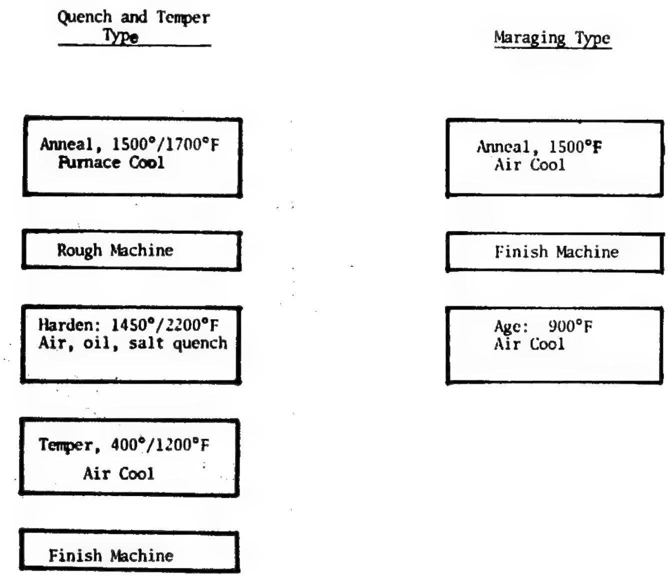


FIGURE 3: Comparative Manufacturing Sequence for Part Production Using a Standard Quench and Temper Steel and a Maraging Alloy

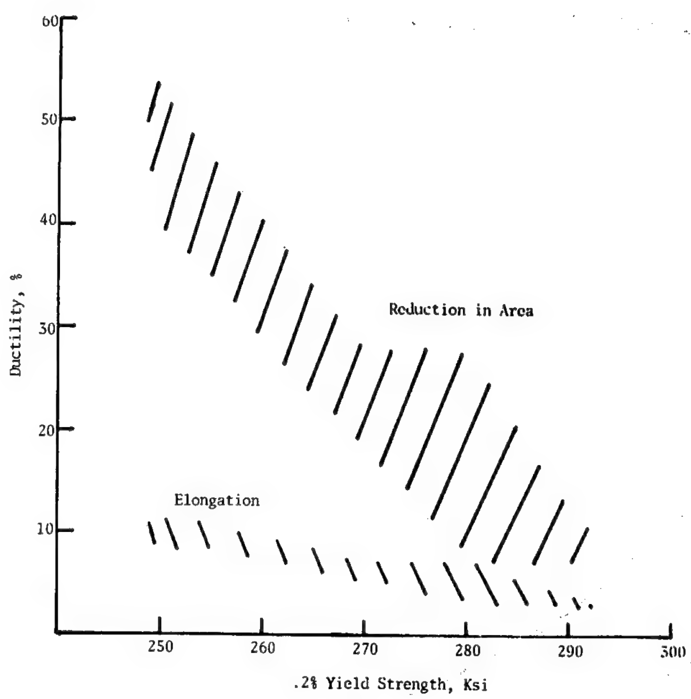


FIGURE 4: Transverse Tensile Data Illustrating the Correlation Between Ductility and Strength Level for the Maraging Steels (12'' Square Billet)

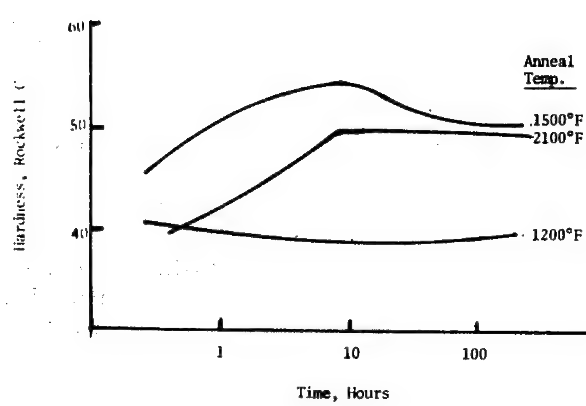


FIGURE 5: Effect of Aging at 900°F on Hardness After Initial Annealing At the Indicated Temperatures

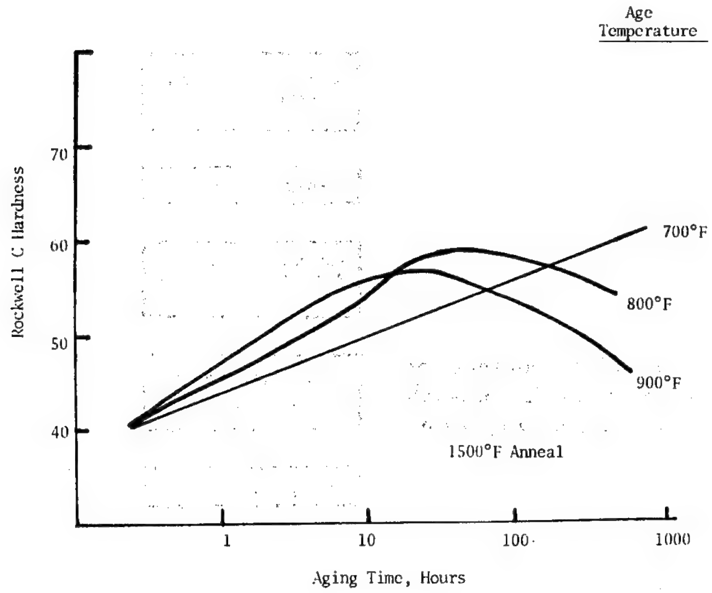
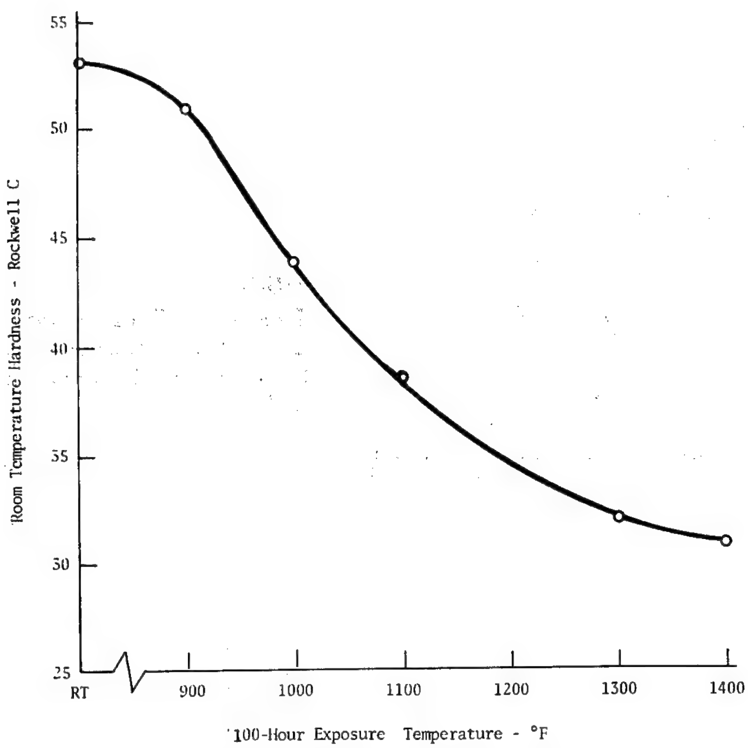


FIGURE 6: 280 Ksi Type Maraging Steel Aging Characteristics



Note: 1) All samples initially hardened by solutioning at 1500°F and aging for 3 hours at 900°F.

2) Individual samples were used for each exposure temperature.

FIGURE 7: Room Temperature Hardness Versus 100-Hour Exposure Temperature 18% Ni, 280 ksi Maraging Steel

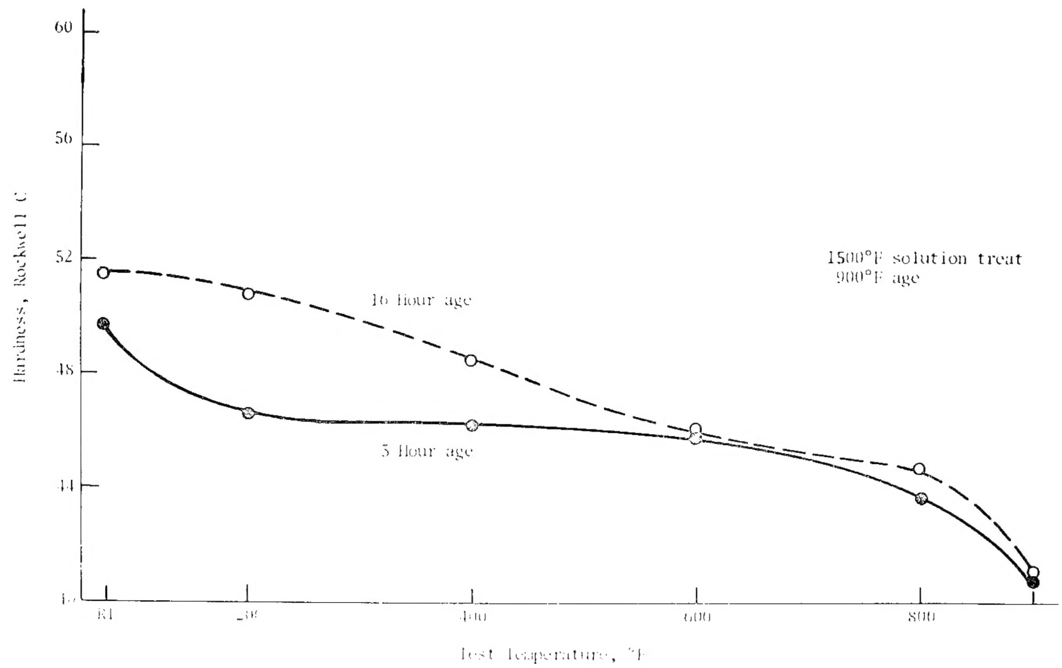


FIGURE 8: Elevated Temperature Hardness Data 18% Ni, 250 Ksi Grade Maraging Steel

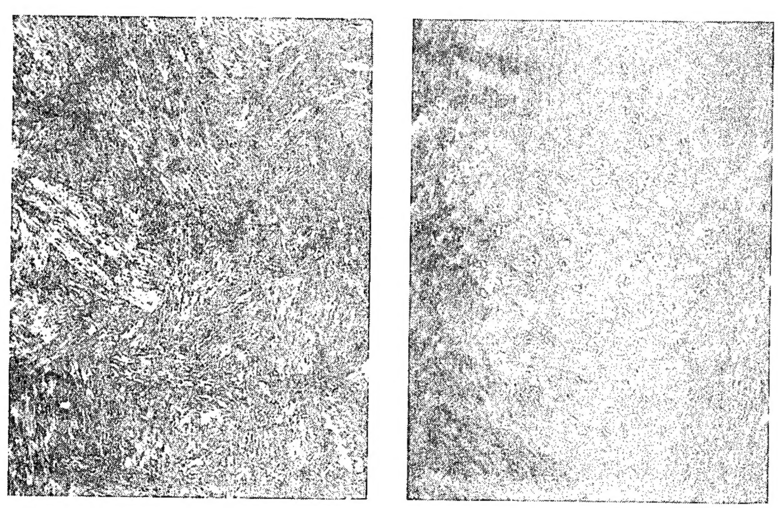


FIGURE 9: Photomicrographs illustrating austenite reversion as a function of 900°F aging time for the 250 ksi grade of 18% Ni maraging steel. Etchant: Nital Mag: 1000X

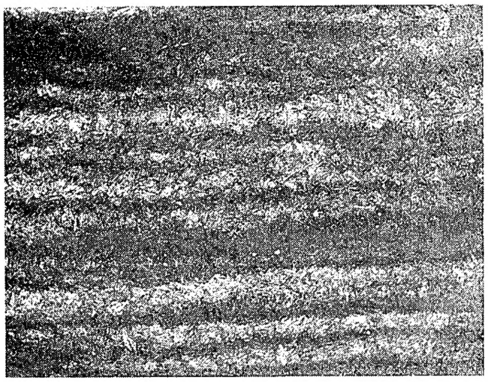


FIGURE 10: Photomicrograph illustrating alloy segregation characteristics of the higher strength maraging alloys.

FIGURE 11: Photomicrograph illustrating the "banded" condition synonomous with the maraging steels.

FIGURE 12: Photomicrographs illustrating the effect of melting practice upon the amount of titanium compounds present in the matrix of the maraging steels.

INITIATION FEE MUST BE ATTACHED FOR PROCESSING.

SOCIETY OF PLASTICS ENGINEERS, INC.

65 Prospect Street, Stamford, Conn. 06902

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I hereby make application for { ☐ admission into ☐ reclassification within ☐ reinstatement in } the Society of Plastics Engineers, Inc. in the grade of membership indicated below for which I believe I am qualified. (See instructions or reverse side.)

Grade	Initiation Fees	Annual Dues	Foreign Dues
☐ Senior Member	$10.00	$20.00	$17.50
☐ Member	10.00	20.00	17.50
☐ Affiliate Member	10.00	20.00	17.50
☐ Student Member	None	5.00	5.00

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(Geographical location. See listing on reverse side.)

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(First) (M.I.) (Last) (Citizen of) (Birthdate)

Please fill in both addresses and **CHECK THE ONE TO WHICH YOUR MAIL SHOULD BE ADDRESSED.**

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1. ______________________________ Address ______________________________
2. ______________________________ Address ______________________________
3. ______________________________ Address ______________________________

STATEMENT OF COLLEGE WORK

Years Attended		Institution	Major and Minor	Degree	Experience Credits See reverse side
From	To				
				Total Education Experience Credits	

RECORD OF QUALIFYING EXPERIENCE IN PLASTICS

Dates				Give your title, name and location of employer, and name of immediate superior for each position. List in chronological order. Describe duties fully and state briefly any important engineering work you have done in in each position. If space is not sufficient, use a separate sheet.	Time in years and months
From		To			
Mo.	Yr.	Mo.	Yr.		

I certify that the statements made in this application are correct. I agree, if elected, to be governed by the Constitution and By-Laws of the Society, and to promote the objective of the Society.

Total qualifying years of experience. ______

Total education and qualifying experience credits. ______

NATIONAL CREDENTIALS COMMITTEE USE ONLY	
Approved (Signature)	Date
Approved (Signature)	Date

______ Date of Application

______ Signature in ink.

COMPLETING THE APPLICATION

Grade of Membership . . .

Membership grades are based on experience credits which are earned as follows:

1. **Experience credits earned for education.**

Doctorate in science or engineering subject:	**6 credits**
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Other degree in non-science or non-engineering subject:	**2 credits**

Maximum credits allowable for education shall be six (6).

When filling in the "Statement of College Work" on the reverse side of this application, please place the corresponding number of credits earned in the right-hand column.

2. **Experience credits** for qualifying experience in plastics or plastics engineering are earned at the rate of one (1) per year, e.g. 5½ years of qualifying experience = 5½ credits. *Please detail carefully the engineering skill required for **each position** to help the Credentials Committee judge experience as "qualifying."*

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When you have determined the number of credits which you believe you have earned consult the following membership grade requirements. Indicate on the reverse side the grade of membership for which you believe you are qualified.

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Senior Member	Minimum of twelve (12) experience credits and maintained continuous membership in the Society for a minimum of two (2) years.
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Student Member	Regularly enrolled student (full- or part-time) in a course of study in plastics and between the ages of 16 years and 26 years, inclusive.

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Please check off the principal activity of your company under either Manufacturing or Non-Manufacturing.

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6. ☐ Fabricated Metal Products and Housewares
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16. ☐ MANUFACTURING, other than above. Please specify ____

17. ☐ Plastics Custom Molders, Extruders, Laminators, and Fabricators
18. ☐ Plastic Materials
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25. ☐ Transportation Operating Companies
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28. ☐ Doctors, Lawyers and other Professionals
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